GOLD MINERALIZATION AT
THE GOLDEN BLOCKS
GOLD FIELD

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of
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by
A.W. Burgess

University of Canterbury
1978
Frontispiece  My two faithful companions in the field;
Jim Sweeny and GG3115.
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In the Golden Blocks area, vein-type gold and sparse sulphide mineralization occur in slightly metamorphosed, complexly deformed, Lower Ordovician sandstones and mudstones.

Primary gold mineralization is associated with quartz veins in deformation zones occurring near the contacts of several carbonaceous mudstones. Eighty-five percent of the gold production from the area has come from five workings confined to the stratigraphically lowest, most widespread occurrence of mudstone. The distribution of primary mineralization is controlled by two factors:

1. The deposition of gold by solution - wall rock interactions between mudstone sediment constituents and mineralizing solutions

2. The confinement of lodes formed within mudstones to those portions of deformation zones which are close to or intersect sandstone units.

Productive gold deposits are confined to those primary lodes, permeable to supergene solution movement, which intersected the Upper Cretaceous weathering surface. The Ordovician sediments hosting the ore-bodies are only weathered to depth along deformation zones, and primary ore values appear to be enriched to workable grades by supergene processes.
Figure 1-1 Location map.
CHAPTER I

INTRODUCTION

1. LOCATION

The area mapped (see figure 1-1) comprises approximately 20 km$^2$ within the Kahurangi Sheet (1:63,360 series, Bishop 1968). It is bounded to the west by Sandhills Creek, to the south by the north branch of Sandhills Creek and by Big Slaty Creek to the east. The southern edge of Lake Otuhie forms the northern margin. This region is referred to as the Golden Blocks area. The nearest township is Mangarakau, some 8 kilometres to the north-east.

2. PHYSIOGRAPHY

The physiography is typically rugged and heavily bushed. Relief attains a maximum altitude of only 500 metres; however, streams are deeply incised with gorges and waterfalls common. The bush is particularly dense in the vicinity of the Golden Ridge and Malones Creek (see map 1) because of regeneration of the bush after extensive burning during early prospecting days. Mountain beech, silver beech and rimu are particularly common. Above an elevation of 300 metres bush is replaced by tussock and stunted
manuka. The climate is generally mild all year round; the rainfall varies between 150-200 cm per year.

3. PREVIOUS WORK

The earliest studies of the Golden Blocks area by geologists concerned the economic aspects of auriferous quartz lodes. Cox (1882) found that auriferous lodes were associated with two belts of slate which were separated by a cherty sandstone. He reported that the rich lodes at the Morning Star (Map 1, grid reference 629,579) and Old Golden Ridge Mines (627,561) occurred in the lower slate belt while only minor auriferous lodes were associated with the upper slate unit. Cox's description suggested a fissure-type lode at the Old Golden Ridge Mine. In contrast, a study of this mine by Park (1890) indicated that small discontinuous auriferous quartz veins were confined to a thin sheared band of slate. He also observed at this mine, that gold values decreased with depth. Park considered that auriferous occurrences in the Golden Blocks and surrounding areas were associated with a single widespread slate unit. Bell et al. (1907) reported that the auriferous quartz lodes at all productive mines in the Golden Blocks area were confined to a narrow band of argillites. They also suggested that the workings of the Friday Creek Mine (838,985 Kahurangi Sheet, Bishop (1968)), occurred within this argillite band. Bell et al. also considered that supergene processes were important in enriching the primary tenor of the lodes to economic grades.
Cox (1882), Park (1890) and Bell et al. (1907) all concluded that the gold mineralization in the Golden Blocks area was associated with quartz veins confined to slate or argillaceous lithologies. However, the above authors disagreed with respect to the stratigraphic distribution and relationships of auriferous occurrences in this area. Park (1890), and in particular Bell et al. (1907), recognised the role of supergene enrichment processes in enhancing the tenor of quartz lodes in this area.

Recent studies in the Golden Blocks area have concentrated on the stratigraphy and structure of the rocks; with little written regarding the auriferous lodes in this area. Bishop's (1968) mapping of the Kahurangi Sheet resulted in changes to, and re-organisation of, Grindley's (1960) stratigraphic divisions. Bishop's (1968) map indicated that mine workings at the Aorangi (628,543), Anthill (626,551), Golden Ridge (625,567), New Find (625,568) and Morning Star Mines (629,579) occurred within the Aorangi Mine Formation, while the mineralized zone at the Friday Creek Mine (838,985 Kahurangi Sheet, Bishop (1968)) occurred within the Sandhills Creek Formation. Detailed studies of grapholitic fauna in the Golden Blocks area by Cooper (1969) enabled further subdivision of Bishop's (1968) units and resulted in the recognition that the sequence in the Golden Blocks area was overturned.
4. SCOPE OF THIS STUDY

The aim of this thesis is to investigate the processes and factors controlling the formation and distribution of auriferous ore bodies in the Golden Blocks area; an aspect of the economic geology not considered by previous geologists. This project is primarily concerned with the factors controlling the deposition and formation of the ore deposits. The possible source and transport mechanism of the gold mineralization is only briefly considered. Data for this investigation was derived mainly from field studies. Microscope and laboratory work was used extensively to study the quartz veins.

The presentation of research in this thesis is as follows:

1. The general geology of ore deposits (stratigraphy (Chapter II), structure (Chapter III) and structure and stratigraphy of auriferous occurrences (Chapter IV)).
2. A description of the gold mineralization (general description of the quartz veins (Chapter V), the processes of vein formation (Chapter VI) and supergene enrichment (Chapter VII)).
3. A discussion of the processes and factors controlling ore body formation (Chapter VIII).
4. Summary and recommendations (Chapter IX).
TABLE 1-1  Returns of Gold Mines in the Golden Blocks Area

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<th>Company</th>
<th>Mine</th>
<th>Gold Yield</th>
</tr>
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<tr>
<td>Golden Blocks (Taitapu) Limited</td>
<td>Aorangi</td>
<td>26,939 oz</td>
</tr>
<tr>
<td>Golden Ridge Company</td>
<td>Anthill</td>
<td>4,600 oz</td>
</tr>
<tr>
<td></td>
<td>Golden Ridge</td>
<td>5,400 oz</td>
</tr>
<tr>
<td></td>
<td>New Find</td>
<td>2,000 oz</td>
</tr>
<tr>
<td></td>
<td>Fault Adits</td>
<td>Small quantity of good stone.</td>
</tr>
<tr>
<td>Morning Star Company</td>
<td>Old Golden Ridge</td>
<td>Combined total of 6,000 oz (later taken over by the Golden Ridge Company)</td>
</tr>
<tr>
<td></td>
<td>Morning Star</td>
<td></td>
</tr>
<tr>
<td>Morning Star and Golden Ridge Companies</td>
<td>Open Cast Workings</td>
<td>500 oz</td>
</tr>
<tr>
<td>Wilke and Party</td>
<td>Friday Ck.</td>
<td>800 oz</td>
</tr>
<tr>
<td>Wilke and Party</td>
<td>Tinnes Ck.</td>
<td>Small quantity of gold.</td>
</tr>
<tr>
<td>Unknown</td>
<td>Independence Mine</td>
<td>Small quantity of gold.</td>
</tr>
</tbody>
</table>
5. MINING HISTORY

Approximate returns for producing mines in this area are shown in Table 1-1. Much of the information presented below is from J.N.W. Newport's book "Collingwood"; readers are referred to this book for further general information on this area. A provincial newspaper, The Golden Bay Argus was his major source of information.

Gold was first discovered by Maoris in Slaty Creek in 1881 (Argus July 1862). Alluvial mining was a feature of this district over the next ten years, with rich finds being made in Malones Creek (855995), Tinnes Gully (852995), Cockabully Gully (825975) and Independent Stream (815945). (For locations see Kahurangi Sheet). The Argus (June 1872) reported that a battery had been set up to crush quartz taken from workings in the upper reaches of Friday Creek. The battery, a five head stamp, was brought by Wilke and party from Charleston. This battery, which used water power, was connected to the mine by a small tramway. £3,000 of gold was won quickly from this mine, but the lode was lost in a slip and work abandoned.

In 1884 auriferous cements were found in Slaty Creek. The Morning Star Company bought a small five head stamp which had been in use at Fishers Creek, a tributary of Appo's Gully, on the Collingwood field (Argus, 31 March 1874). The battery was placed near
the junction of Slaty and Coffee Creeks, at a bend in
the gorge (see Map 1). The battery was driven by a
large water wheel, the water for which was flumed from a
dam near the top of the Big Slaty gorge, near its junction
with Mutton Town Creek (see Map 1). The cements were
worked by open cast mining and £1,650 over and above
working expenses was returned to the Morning Star Company.
The tracing of lode stones in cements (Park, 1890)
resulted in the finding of the Golden Ridge Mine, later
referred to as the Old Golden Ridge Mine. The mine was
run by a company of the same name. Work also started
on the Morning Star Mine about this time. After work
ceased at the Old Golden Ridge Mine, this Company went
back to working cements. The Old Golden Ridge Company
bought the Morning Star Mine from which it won good gold.
Gold to the value of £22,000 was won by the Old Golden
Ridge Company during its working life. (This presumably
includes returns from both the Old Golden Ridge and
Morning Star Mines.)

When James MacKay purchased the West Coast from
the Maoris, some 88,000 acres which cover the area
between West Wanganui Inlet and Kahurangi Point, were
set aside as a Maori reserve. This reserve was aptly
named Tae Tapu or Taitapu; which translated means
"forbidden territory". In 1881-1882 this land was
purchased from its Maori owners by a Wellington
syndicate, for approximately £10,000. In 1895, the
property was placed on the London Stock Exchange and
sold for £110,000 to a syndicate, later to be called Taitapu Estates Company.

This company commenced active prospecting of the area in 1896 and was responsible for the majority of subsequent mining operations. Charles Edmond was in charge of work and a company town, Parkeston was built on the western side of the Paturau river. Williams (1974) reports that the title to the land which is still held by the Taitapu Estates Company is unusual in that it gives this company claim to the mineral rights of the noble metals within the Golden Blocks area. Williams (1974) suggests that the anomalous form of the land title has been a block to recent prospecting within the area.

The Argus reports that in December 1885 Joe Malone and the Lunn Brothers discovered auriferous outcrops which were later to become the Golden Ridge Mine. Each was paid a reward of £100. By August 1896 £20,000 worth of gold had been taken from this mine. The Golden Ridge Mine was extensively developed with two adit levels, and the reef varied between 2 in. to 8 ft. This reef yielded up to 131 oz per ton. (Papers and reports relating to Minerals and Mining, 1897.) The Taitapu battery was then built at the bottom of the Big Slaty gorge to crush ore from this mine. The water to power the battery was tapped from the original supply to the old Golden Ridge battery, (see map 1) from which it was taken via a long drive
to the slopes west of the Slaty Creek gorge. Here it was held in a tank and piped the final distance to the battery. The ore was transported by aerial from a hopper located near the New Find Mines (see Map 1). The total cost of the battery, aerial and water races was £14,000. After opening in February 1898, the battery operated for only a few weeks before work stopped because of poor ore reserves at the Golden Ridge Mine and storm damage.

In August 1900 (The Argus) tenders were called for the transport of ore from the Anthill mine to the aerial hopper near the New Find Mine. To aid the transport of ore, a 400 ft tunnel was driven through the ridge. This was finished in October, 1902. £17,000 worth of gold was won from this mine. Reports at this time indicate that the Taitapu battery also crushed quartz from the Old Golden Ridge Mine (or new adits near this mine). About 1903 the New Find Mine was discovered; 90 tons of quartz yielded 130 oz of gold. Crushing at the Taitapu battery stopped in August, 1906.

In 1897, three companies, the Australasian Gold Trust, the Pioneer Company of London and West Australian Syndicates formed a syndicate and were granted a licence to prospect two blocks south of the Golden Ridge. In 1898 extensive tunnelling was carried out just south of the Anthill Mine; however,
water filled the workings and stopped operations. In the southern most block, a drive (at the site of the Aorangi Mine) yielded auriferous quartz at $3\frac{1}{2}$ oz per ton. In September 1898 the licence was taken over by a new company, The Golden Blocks (Taitapu) Limited, a subsidiary of Taitapu Estates. A trial crushing of ore showed good results and in April 1900 a new plant with a total of 8 stamps was opened. The battery was driven by a steam engine, the coal for which was obtained from seams in the middle reaches of Jimmy's Creek. This coal was transported to the battery via a tramway and aerial. Ore from the mine was moved via a tramway. In 1905, the mine manager, Mr Johnson, was arrested for the theft of gold from the mine which he had originally discovered.

The mine plans shown in Bell et al. 1907 indicated that ore was stoped over 3 levels. The mine manager, F. Giles died in 1909 and as a result the mine closed until November 1910. After re-opening, ore was stoped from the third level to the surface. In March, 29th, 1911 the battery was burnt down resulting in a cessation of crushing for that year. Preparations were made for the sinking of a shaft for a fourth level. In 1911, a thirty metre inclined shaft was sunk. It is reported (Papers and reports relating to minerals and mining 1912) that "satisfactory results" were obtained from this shaft.
I would like to thank the following people for assistance and encouragement during research for this thesis.

My parents for their encouragement and patience and in particular my father, who spent many hours proof reading this manuscript.

J. Sweeny for his hospitality and stimulating company on weekends out of the field and also for the use of his hut at The Golden Blocks Goldfield.

J. Campbell for numerous discussions and for critical appraisal of aspects of this thesis relating to structure and map presentation.

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Val Cook whose expertise and attention to detail is reflected in the quality of typing and layout of this thesis.

Special mention must be made of the Mighty A, CG 3115, for faithful service on the long trips to and from my field area and during cross country runs in the field.
CHAPTER II

STRATIGRAPHY

1. INTRODUCTION

Map 2 (back pocket) shows the distribution of Paleozoic and Tertiary rock units in the Golden Blocks area. Figures 4-1, 4-6 and 4-10 depict in greater detail the distribution of Paleozoic stratigraphic units near to known occurrences of gold mineralization.

Descriptions of the sedimentary sequences follow McKee and Weir (1953) for stratification types, Conybeare and Crook (1968) for sedimentary structures, and Folk, Andrews and Lewis (1970) for sediment texture and composition.

Detailed sedimentological description is confined to Paleozoic sediments, as gold mineralization is associated with these sediments. Sediment textures were determined by thin section studies (U.C. 8011 - U.C. 8068) and sub-microscopic micas and carbonates identified by x-ray diffraction. Only field descriptions are given for Tertiary sediments.

The textures of Paleozoic sediments in the Golden Blocks area are only slightly modified by post-diagenetic and metamorphic processes, with the development of chlorite, sericite and muscovite parallel to cleavage and the growth of sparse albite porphyroblasts
<table>
<thead>
<tr>
<th>Grindly 1961 Group Formation</th>
<th>Bishop 1968 Group Formation</th>
<th>Cooper 1969 Formation Member</th>
<th>This paper 1976 Group Formation Member</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pakawau</td>
<td>Pakawau</td>
<td>Pakawau</td>
<td>Pakawau</td>
</tr>
<tr>
<td></td>
<td>Golden Bay</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aorere</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aorangi Mine</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Webb</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Haupiri</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sandhills CK</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2-1 Summary of Paleozoic Stratigraphy
The absence of metamorphic biotite in mudstone lithotypes suggests that temperatures during metamorphism did not attain $410^\circ C$ (1-4 K bars) (Winkler (1967, 1974)). This, together with the occurrence of albite porphyroblasts (Harker (1932)) suggests that the metamorphic grade of Paleozoic sediments in this area is of lower greenschist facies. The poor expression of metamorphism in the Paleozoic sediments prevented further work on this aspect.

Paleozoic stratigraphic terminology within the Golden Blocks area is reviewed in Table 2-1. Bishop's (1968) re-organisation of Grindley's (1961) stratigraphy resulted in limiting the extent of the Aorere Group and the recognition of the Golden Bay and Haupiri Groups. Detailed studies of graptolitic faunas enabled Cooper (1969) to divide Bishop's Aorangi Mine Formation into four members. The Roaring Lion Formation and the Golden Bay Group were subdivided by Cooper into two informal formations named A' and B'.

Cooper (1969) considered that the sequences at the type areas for the Golden Bay Group and the Roaring Lion Formation in the Roaring Lion Valley area were insufficiently distinctive for these formations to be recognizable in the Golden Blocks area, some twenty-five miles to the north. Cooper omitted to redefine the upper limit of the Aorere Group. Stratigraphic units used in this thesis are basically those proposed by Cooper.
Figure 2-1 Geology of the Kahurangi Sheet surrounding the Golden Blocks area. The majority of geologic contacts were determined by Bishop (1968). Modifications to the distribution and stratigraphic position of the Sandhills Creek Formation were made by the writer.
Table 2-1 shows two innovations to the Paleozoic stratigraphy. These changes concern
1. the stratigraphic position of the Sandhills Creek Formation,
2. the recognition of a new stratigraphic unit: the Mine Bed.

(1) **The Stratigraphic Position of the Sandhills Creek Formation**

Detailed faunal studies by Cooper (1969) showed that the steeply westward dipping Aorangi Mine Formation was overturned. Bishop (1968) believed that the Webb and the Sandhills Creek Formations to the west were part of this inverted sequence, the Sandhills Creek Formation representing the oldest unit.

Mapping in 1974 by Cooper and the author in the Sandhills Creek area revealed that a structural feature mapped by Bishop as a fault was in fact the axis of an inclined megascopic fold. Younging directions obtained from sedimentary structures indicated that the gently (westward) dipping beds to the west of the fold axis were right way up, whereas the steeply (westward) dipping beds to the east of the fold axis were overturned. The Sandhills Creek Formation, previously only located to the west of the megascopic fold axis (Kahurangi Sheet S2, Bishop 1968), was also observed to outcrop to the east of this axis, between the Aorangi and Webb Formations. The revised stratigraphic distribution of the Sandhills Creek Formation is shown in Figure 2-1.
It follows that this formation is not the oldest unit in the Paleozoic sequence but that its stratigraphic position is intermediate to the Aorangi Mine and the Webb Formations.

The contacts between this lithologically distinctive unit and adjacent formations are redefined as follows: The lower and upper limits of the Sandhills Creek Formation are placed at the stratigraphically highest or lowest occurrence of white spotted grey-green muddy sandstone: (sericitic) feldspathic micaeous sub-litharenite or litharenite.

(2) The Mine Bed: A New Stratigraphic Unit

Lithologically distinctive mudstone beds which outcrop near the top of Member AM₁ and which are widely distributed and associated with the mine workings of three productive gold mines, are here recognised as a new lithostratigraphic unit: The Mine Bed.

Bell et.al. (1907) appear to have recognised a similar group of mudstone beds, although they assigned no formal name at that time. Bell et.al. who extended and clarified the work of Cox (1882) and Park (1890), observed the following sequence at several mine localities:

"The rocks met within the various mine workings, are in ascending order, fossiliferous argillites in considerable thickness, a narrow band of quartzitic granuwacke, a coal-black carbonaceous argillite, frequently siliceous and never more than 20 ft in thickness and finally quartzitic granuwacke of considerable thickness."

Bell et.al (1907) Pg 90.
<table>
<thead>
<tr>
<th>Present Stratigraphic Units</th>
<th>Sediment Texture</th>
<th>Lithologic Units Bell et al.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Member AM$_2$</td>
<td>Siltstone</td>
<td>Argillites of considerable thickness</td>
</tr>
<tr>
<td></td>
<td>Mudstone</td>
<td></td>
</tr>
<tr>
<td>Mine Bed</td>
<td>Sandstone</td>
<td>Narrow band of Quartz-litic granwacke</td>
</tr>
<tr>
<td></td>
<td>Mudstone</td>
<td>20ft coal-black carbonaceous argillite</td>
</tr>
<tr>
<td>Member AM$_1$</td>
<td>Sandstone</td>
<td>Considerable thickness of quartzitic granwacke</td>
</tr>
</tbody>
</table>

Figure 2-2 A comparison between the sequence observed by Bell et al. in mine workings and the present Paleozoic stratigraphic units in the same areas.
The relationships between these lithologic units and present stratigraphic units is shown in Figure 2-2.

Mudstones of the Mine Bed form a lithologic unit 2-45 metres thick. Cream-coloured laminae with wedge shaped terminations (Plate 2-1) are characteristic of the Mine Bed mudstones and allows this lithology to be distinguished from mudstones in Member AM₂. The Mine Bed is defined as follows: The base is placed at the contact of thin to very thin bedded to laminated mudstone with very thick bedded sandstone. The top is placed at the stratigraphically highest occurrence of thin to very thin bedded or laminated mudstones within Member AM₁.

2. PALEOZOIC SEDIMENTS

(1) The Webb Formation (Bishop 1968)

As the extent of this formation is limited to the western most edge of the mapped area, comments refer to the upper-most portions of the formation.

The Webb Formation consists of a monotonous sequence of thick bedded sandstones interbedded with thin to very thin bedded mudstones. Graded bedding, ripple marks, current scour structures (including flute moulds), flame structures and groove moulds are occasionally found.

Poorly sorted sediments dominate, although all degrees of sorting occur. The grain size ranges from medium sand to very fine silt.
Plate 2-1  A sandstone of Member AM₁, containing a laminated mudstone intraclast of Mine Bed lithology. The cream coloured lamination with its wedge shaped termination is distinctive of Mine Bed sediments.
Plate 2-2 Moulds of current scour structures (indicated by arrows, plate a) and groove moulds (plate b) in Sandhills Creek Formation, Soldiers Creek (grid reference 613549).
The dominant constituents of both arenites and lutites are quartz and mica, with minor amounts of pyrite (up to 10%) and siderite (up to 10%). Lutites also contain abundant clay minerals. Large pyrite cubes which vary in size between 5 to 10 mm are abundant in fine sandstones near the top of this unit.

(2) **The Sandhills Creek Formation** (Bishop 1968)

The description below refers to sediments mapped on the eastern side of Sandhills Creek, the western margin of the mapping area. A brief survey along the timber road from Sandhills Creek to Webb Stream (835983 to 839970 Kahurangi Sheet S₂, Bishop (1968)) indicates that the Sandhills Creek Formation is similar to outcrops further to the east.

Within this formation three stratification types are recognized:

1. Thick to thin bedded sandstone forming lithologic units up to 20 metres thick.
2. Thick to thin bedded sandstones interbedded with thin to very thin bedded mudstones.
3. Thin to very thin bedded mudstones forming lithologic units up to 5 metres thick.

Moulds of current scour structures and groove moulds (Plate 2-2) are common; flame structures occur in rare outcrops.
Silty sandstones predominate; sizes range from clay to coarse sand. Poorly sorted sediments are dominant.

Quartz arenites are common while sub-litharenites and litharenites occur sparsely. Plagioclase feldspar is a minor (5-10%) but distinctive component. Most rock fragments are composed of very fine to medium sand size clasts of chert, while some micaceous and zeolitic (?) clasts may represent original volcanic contributions, but the degree of alteration is too great for positive identification. Other constituents are muscovite (5-20%), chlorite (1-10%), and leucoxene (1-2%).

(3) The Aorangi Mine Formation (Bishop 1968)
   (a) Member AM1 (Cooper 1969). The dominant lithology is very thick bedded sandstone. Very thin bedded, laminated and thinly laminated mudstones and thick to thin bedded sandstones occur as sparse lithologic units 3-30 metres thick. Cross-lamination and current scour structures are common.

Poorly sorted sandstones dominate; sediment sizes range from clay to medium sand.

Quartz arenites are common while sublitharenites and litharenites, often with a chert matrix, occur frequently near the top of this member. Rock fragments are predominantly sand sized clasts of chert; rare clasts of micaceous mudstone occur. Arenites similar in composition
Figure 2-2 A N-S orientated cross-section showing the variation in thickness of the Mine Bed. The contact between Member AM₁ and AM₂, shown as a horizontal line, was used as a reference surface. Distances between sections were measured with respect to the N-S trending grid line. Marked portions of Member AM₁ contain clasts of Mine Bed lithologies.
to litharenites of possible volcanoclastic derivation observed in the Sandhills Creek Formation outcrop in a thin irregular unit near the top of Member AM₁. Outcropping in irregular shaped bodies at the top of Member AM₁, and overlying the Mine Bed (see figure 2-3), are chert bearing quartz arenites and sublitharenites which contain angular pebble and granule sized clasts of locally derived sediments (Plate 2-1). Such deposits are probably the result of intraformational erosion. The major constituents of lutites are quartz, clay and muscovite. Pyrite (1-10%) and carbonaceous matter (5-15%) are common minor constituents.

(i) The Mine Bed. This unit consists of thin to very thin bedded and laminated mudstone, interbedded with infrequent beds of thin bedded sandstone. In the middle portions of a measured section at the Aorangi Mine (grid reference 628544) a further stratification type was recognised: thin bedded sandstones interbedded with thin bedded mudstone. Current scour structures and groove moulds are common.

An unconformable contact occurs at the top of the Mine Bed in the Aorangi Mine section, while in other measured sections contacts of this unit are either sheared, faulted or not exposed.

The considerable variation in thickness (see Figure 2-3), may be explained by the following
alternatives:

1. erosion of the top surface of the Mine Bed.
   Intraclasts of the Mine Bed mudstones occur in the overlying sandstones, supporting this explanation.

2. Deposition on an original unconformable surface of high relief.

3. Thickening and thinning of beds by structural processes. An example of sediment repetition caused by faulting occurs at the Aorangi Mine.

The grain size ranges from clay to medium sand and most sediments are poorly sorted.

Lutites are the predominant sediments present, the dominant constituents of which are clay, carbonaceous matter and quartz. Common minor constituents are detrital muscovite (1-10%), authigenic sericite and chlorite (up to 10%), pyrite (up to 5%), siderite (1-2%) and limonite (stains). Distinctive cream-coloured laminae are present in mudstones of the following composition: (sericitic, chloritic) pyritic quartz carbonaceous clay lutite. The laminae are (sericitic chloritic) pyritic quartz clay lutites. Arenites have compositions ranging from sublitharenite (most abundant) to litharenites. The bulk of the rock fragments are composed of chert, which may also form part of the matrix. Sericite and chlorite (up to 10%), leucoxene and sphene (1-2%) are common minor constituents.
(b) Member AM₂ (Cooper 1969). Thin and very thin bedded and laminated mudstones are the dominant lithology. Thin bedded sandstones, although common near the base, occur sparsely in the middle and upper portions of the unit. Occasionally seen are moulds of current scour structures, ripple marks, and small scale cross laminations. In the vicinity of the Aorangi Mine, near the base of this Member, thin bedded sandstones contain angular granule-sized clasts of mudstone clearly derived from adjacent lithologies. Such beds are probably a smaller scale version of intraformational erosion described in Member AM₁. Small cross-cutting sandstone "dykes" which disrupt mudstone lithologies are considered the product of soft sediment deformation.

Mudstones and siltstones are common while silty sandstones occur sparsely. Most sediments are poorly sorted and range in grain size from clay to medium sand.

Quartz, carbonaceous material, mica and clay are major constituents of the lutites. Pyrite (up to 10%), which may form accumulations parallel to bedding 1cm by 6cm, and authigenic sericite are minor constituents. Arenites occur sparsely; quartz arenites predominate, while sublitharenites and litharenites are rare. Rock fragments are dominantly clasts of chert; infrequent clasts of micaceous mudstone are present. Commonly
Plate 2-3 Mounds of scour structures (indicated by arrows) in Member AM3 sediments in opencast workings near the Old Golden Ridge Mine (grid reference 628560).
chert forms the arenite matrix. Minor constituents are pyrite (1-5%) and leucoxene (0-2%).

(c) Member AM₃ (Cooper 1969). Thin and very thin bedded mudstones occur frequently while thick-bedded and laminated mudstone, very thick, thick and thin bedded sandstones outcrop only occasionally. Thick bedded sandstones interbedded with very thinly bedded mudstones are exposed in the vicinity of the Morning Star Mine (grid reference 629561) at the contact with Member AM₄. Current scour moulds (Plate 2-3), graded bedding, and small scale cross laminations occur in sparse outcrops.

The textures of mudstones and sandstones and the composition of lutites is similar to those of Member AM₂. Arenites, which are observed infrequently are predominantly quartz arenites composed of quartz and mica; often arenites contain carbonaceous material (1-10%).

(d) Member AM₄ (Cooper 1969). This member predominantly consists of very thick and thick bedded sandstones. Thin to very thin bedded sandstones, thin to very thin bedded and laminated mudstones outcrop as lithologic units 1 to 10 metres thick near the base and middle of Member AM₄. Current scour structures occur in the thin to very thin bedded sediments.
Sediments are poor to moderately sorted, with sandstone the most abundant lithotype texture seen.

Dolomite and siderite (1-5%) occur sparsely in both lutites and arenites. The lutites are similar in composition to those in Members AM₂ and AM₃. All observed arenites were quartz arenites which contain detrital chlorite and muscovite (2-10%). Other minor constituents are carbonaceous material (0-10%), pyrite (1%-10%), authigenic sericite (2-5%), leucoxene (0-1%), fine to medium sand-sized clasts of chert (0-1%) and limonite (stains).

(4) **Formation A** (Cooper 1969)
(a) **Member A₁** (Cooper 1969). Interbedded thinly laminated, laminated, very thin and thin-bedded sandstones and siltstones are dominant. Occurring near the top of this Member is a very thick-bedded sandstone (7-10 metres). Contorted bedding, cross laminations and current scour structures are common sedimentary structures. Micro-faulting, possibly the result of synsedimentary deformation, occurs in rare outcrops.

Poorly to moderately sorted siltstones, sandy siltstones, and silty sandstones are common lithotype textures.

Lutites are composed of clay (30-50%), quartz (10-40%), detrital micas (20-40%) and carbonaceous
<table>
<thead>
<tr>
<th>Stratigraphic unit</th>
<th>Dominant Stratification types</th>
<th>Cross-bedding</th>
<th>Graded bedding</th>
<th>Irregular intercalations</th>
<th>Ripple Marks</th>
<th>Thin-beddedness</th>
<th>Predominant Texture</th>
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</thead>
<tbody>
<tr>
<td>Member A3</td>
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<td>C</td>
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<td></td>
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</tr>
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<td>Sandy siltstone</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td>S</td>
<td>S</td>
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<td>Sandy siltstone</td>
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<td>Member A1</td>
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<tr>
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<td>C</td>
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<td>Sandhills Creek Formation</td>
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<td>S</td>
<td></td>
<td></td>
<td>Silty sandstone</td>
</tr>
<tr>
<td>Webb Formation</td>
<td>Very thick to thick bedded sandstone interbedded with thin to very thin bedded mudstone</td>
<td>C</td>
<td>C</td>
<td>S</td>
<td></td>
<td></td>
<td>Sandstone</td>
</tr>
</tbody>
</table>

C - Common  S - Sparse.

Table 2-2 Summary of Paleozoic Sedimentation
material (10-30%), while arenites contain quartz (50-90%), micas (10-35%) and generally lesser amounts of carbonaceous material (0-15%) and clay (0-5%). Minor constituents of both lutites and arenites are pyrite (1-10%), leucoxene (0-2%), siderite (0-5%) and sericite (5-20%).

(b) **Member A2** (Cooper 1969). This member consists of thin and very thin-bedded mudstones occasionally interbedded with bedded sandstones.

The dominant texture observed is poor to moderately sorted siltstone with both arenites and lutites similar in composition to sediments in Member A1.

(c) **Member A3** (Cooper 1969). Interbedded thin to very thin sandstones and mudstones occur frequently while very thick-bedded sandstones and laminated mudstones are only occasionally observed. In the upper part of this member, moulds of current scours, groove moulds, graded bedding and flame structures are commonly seen.

Textures and compositions of lutites and arenites are similar to sediments in Member A1 and A2.

(5) **Summary of Paleozoic Sedimentation**

Characteristics of Paleozoic sediments are summarised in Table 2-2. The ages of Paleozoic stratigraphic units is shown in Table 2-3.
<table>
<thead>
<tr>
<th>Stratigraphic units</th>
<th>Age *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Member A3</td>
<td>Upper Darriwillian</td>
</tr>
<tr>
<td>Member A2</td>
<td>Upper Darriwillian</td>
</tr>
<tr>
<td>Member A1</td>
<td>Yapeenian to Lower Darriwillian</td>
</tr>
<tr>
<td>Member AM4</td>
<td>Yapeenian</td>
</tr>
<tr>
<td>Member AM3</td>
<td>Upper Castlemanian to Lower Yapeenian</td>
</tr>
<tr>
<td>Member AM2</td>
<td>Middle Upper Lancefiedian Bendigonian, Chewtonian Lower Castlemanian</td>
</tr>
<tr>
<td>Member AM1</td>
<td>Lower to Middle Lancefiedian</td>
</tr>
<tr>
<td>Sandhills Creek Formation</td>
<td>Middle Lancefiedian to Pre Lancefiedian</td>
</tr>
<tr>
<td>Webb Formation</td>
<td>Pre Lancefiedian</td>
</tr>
</tbody>
</table>

* Age determined by Cooper (1969) 1975

Table 2-3 Ages of Paleozoic stratigraphic units.
The marine nature of the sequence is suggested by the lack of deposits or features characteristic of fluviatile or aeolian environments and the presence of graptolites, a pelagic marine fossil.

Stratification types and sedimentary structures in were insufficiently studied to gain information with respect to depositional conditions. A consistent NE-SW current orientation throughout the sequence was determined by simple unfolding of the orientations of groove and scour structure moulds.

The variation over a short distance in the thickness of the Mine Bed (Member AM₁, Figure 2-3) as well as the irregular shaped deposits of locally derived clasts confined to the thicker portions of the sandstone sediments overlying this unit, are features unlikely to be observed in a typical turbidite sequence. This observation applies only to sediments near the contact of Members AM₁ and AM₂.

The predominant textures of important stratigraphic units are shown in Table 2-2; conglomerates are not present.

Arenites are commonly micaeous quartz arenites; sublitharenites and litharenites occur sparely. The dominant constituents of lutites are clay, quartz and mica. Carbonaceous material (10%-25%) is present in lutites and rare arenites in the Aorangi Mine and
Carbonaceous matter is best preserved in reducing or stagnant conditions (Folk 1968). Pyrite also forms in similar conditions. This mineral is a common minor constituent (1-5%) of both arenites and lutites throughout the sequence. It is difficult to envisage how the carbonaceous material present in sediments of the Aorangi and A Formations formed in stagnant conditions when sedimentary structures present in these formations indicate the action of traction currents. Such problems are only resolved by detailed depositional studies, beyond the scope of this thesis.

3 Tertiary Sediments

Sediments of the Pakawau Group of late Cretaceous to early Tertiary age (Bishop 1967) unconformably overlie Paleozoic sediments (Map 2). Pakawau Group sediments were deposited on a surface of considerable relief (up to 100 metres). Weathering of Paleozoic lithologies occurs to a depth of 2 to 10 metres below this surface, and to greater depths (up to 30 metres) along faults, shears and fold axis and other zones of high permeability.

The basal beds of the Pakawau Group consist of poorly-bedded muddy sands, with angular and subangular clasts of sediments clearly derived from Paleozoic sediments. The clasts vary in size from granules to boulders; pebbles and cobbles predominate.
Quartz granules are common. In the hollows of the weathering surface these basal sedimentary breccias are up to 30 metres thick, whereas on the steeper slopes, such as the slopes of Baldy (grid reference 628567) only a thin (less than 2 metres thick) discontinuous mantle of sediments occur. This mantle consists of angular granule to cobble-sized clasts of Paleozoic lithologies, quartz and an orange mudstone set in a matrix of siliceous cemented sandstone. Outcropping above the basal beds in hollows or basins in the weathering surface are coal beds up to 2 metres thick. Interbedded with these coal measures are thin-bedded sandy mudstones which contain fragments of plant and carbonaceous material. A thick sequence of thin to thick bedded sandstone, which contains quartz granules, thick to very thin bedded blue grey and cream mudstones, and thin-bedded coal beds outcrop above the coal measures and basal sedimentary breccias. Scour and fill structures and cross laminated beds are commonly seen in the mudstones. An unconformable contact between these mudstones and Paleozoic sediments occurs in the north-west margin of the map area.
1. INTRODUCTION

Structural data recorded during mapping of the Golden Blocks area is represented on Maps 3, 4 and 5 (back pocket, scale 1 cm = 80 m).

Usage of structural terms follows Bishop (1968) and Fleuty (1964) for terms describing the dip of axial surfaces, the plunge of fold axes and the inter-limb angle of fold structures.

Penetrative planar structures such as bedding and cleavage are denoted by the letter S and a subscript which indicates the relative age of one cleavage with respect to the other. Since all phases of folding do not necessarily produce new planar structures then, unless otherwise stated, $S_2$ is not necessarily correlated with $F_2$.

- $S_0 = $ bedding
- $S_1 = $ 1st recognised cleavage
- $S_2 = $ 2nd recognised cleavage ($S_1$ folded about this cleavage.)
- $S_3 = $ 3rd recognised cleavage ($S_1$ and $S_2$ folded about this cleavage.)
Figure 3-1. Various interpretations of the structure of the Golden Block Area.

A. Bell et. al. (1907)
B. Benson et. al. (1936)
C. Cooper (1969)
Lineations are given a letter \( L \) with subscript denoting age, for example:

\[
\begin{align*}
L_1^0 &= \text{intersection of } S_0 \text{ and } S_1 \\
L_2^0 &= \text{intersection of } S_0 \text{ and } S_2 \\
L_2^1 &= \text{intersection of } S_1 \text{ and } S_2
\end{align*}
\]

Bell, Webb and Clark (1907) believed that strata in the Golden Blocks area forms the eastern limb of a N-S trending syncline which had a slight southerly plunge. North of the Golden Ridge, this syncline was thought to plunge N-E. Benson, Keble, King and McKee (1936) stated that:

"The general structure of the region may be explained as an easterly overturned anticline and syncline, broken by strike faulting. The soft thin graphitic lower Castlemanian beds are seen to have acted as a thrust fault."

Cooper (1969), aided by more detailed faunal studies, found that the sequence was continuous but overturned. He postulated the presence of megascopic fold axes to the east and west of the Golden Blocks area. Cooper recognised two further periods of folding, not however, on the scale envisaged by Benson et al. (1936). Discrepancies in section thickness led Cooper to believe faults parallel to strike of the sequence were present. The interpretation of the structure of the Golden Blocks area made by Bishop (1968) during mapping of the Kahurangi Sheet is similar to that proposed by Cooper (1969). The east-west orientated cross sections shown in figure 3-1
represent the different interpretations held by the authors discussed above, on the structure of the Golden Blocks area.

2. STRUCTURAL ELEMENTS FOUND IN THE GOLDEN BLOCKS AREA

The following categories of structure are recognised in the Golden Blocks area.

1. Penetrative planar structures.
2. Linear structures.
3. Megascopic folds.
4. Mesoscopic folds.
5. Minor folds.
6. Faults and shear zones.
7. Joints.

In this section the structural elements in the categories above are described and their relationships to other categories discussed.

(1) Penetrative Planar Structures

Four categories of penetrative planar structures were recognised during mapping of the Golden Blocks area.

(a) Bedding
(b) A slaty cleavage
(c) A N-S striking cleavage
(d) An E-W striking cleavage.
(a) **Bedding.** The main criterion used to define bedding was grain size distribution; however, in massive shale units, pyritic accumulations were often used to define bedding. Bedding can be easily defined in most river outcrops, except in massive outcrops of sandstone of uniform grain size. These massive sandstone units make up approximately thirty-five percent of the sequence within the Golden Blocks area. The distribution and attitudes of bedding measurement are shown on Map 2.

(b) **Slaty Cleavage.** In mudstones the slaty cleavage shows a well developed fissility which, in thin section, is represented either by a mineral alignment of mica flakes or by thin lamellae of carbonaceous material. The development of these carbonaceous lamellae is a feature distinctive of this cleavage. In a sandy mudstone from Member A_3 (U.C. 8068) it was possible to demonstrate that these lamellae were the result of pressure solution effects. Slaty cleavage attitudes are shown on Map 3.

(c) **North-South Striking Cleavage.** In sandstones present in the Golden Blocks area, the N-S striking cleavage is characteristically a fracture cleavage with well developed fractures usually 1mm to 20mm apart, along which the rock will split. However, in mudstones, this cleavage is similar to, but weaker than, the slaty cleavage described earlier. Cleavage attitudes may fan within an outcrop. The N-S striking cleavage generally dips at moderate angles to the west and the location and attitudes
of cleavage measurements are shown on Map 4. In this area the N-S striking cleavage is the second penetrative structure recognised because it is developed parallel to the axial planes of mesoscopic folds which refold the earlier slaty cleavage (see section 4(a)).

(d) **East-West Striking Cleavage.** The E-W striking cleavage has morphological characteristics similar to the N-S striking cleavage described earlier. This cleavage is poorly developed and distribution is restricted to the vicinity of the Aorangi Mine (Map 5). The cleavage has a moderate southward dip and a similar orientation to the axial planes of E-W trending mesoscopic folds (see section 4(b)).

(2) **Linear Structures**

Lineations seen in the field were difficult to measure because of poor light conditions at most outcrops. Therefore data used in stereographic analysis were gained, not from field measurement, but from determinations of bedding/cleavage and cleavage/cleavage intersections on a stereonet.

(3) **Megascopeic Folds**

(a) **The Grand Sandhills Creek Megascopeic Folds.** Mapping of localities near Sandhills Creek in 1974, by Cooper and the writer, revealed an anticlinal hinge about which bedding and superposition directions change. For previous discussion see Chapter Two Section 1-1. The
Figure 3-2. A cross-section along Shot Creek.

Figure 3-3. A diagrammatic section of the hinge zone of a N-S trending fold showing cleavage and bedding relationships.
scale of Figure 2-1 reveals the megascopic nature of this fold structure, named the Grand Sandhills Creek anticline.

Figure 3-2, a cross section drawn parallel to Shot Creek (grid reference 611543) reveals the close axial angle, angular hinge and anticlinal nature of the megascopic fold. In Shot Creek, the axial plane of this fold may be defined to within two metres, within which, intense shearing has taken place. At this locality the extreme angularity of the hinge area may be explained by shearing along the axial plane, removing part of the hinge area.

Figure 3-2 also indicates that the slaty cleavage attitudes are parallel to the axial plane of the megascopic fold projected from bedding attitudes. Cleavage attitudes indicate that the axial plane of this fold is inclined moderately to the west and strikes NNW-SSE. Figure 3-4, a pi diagram of poles to bedding attitudes measured in Shot Creek and the North Branch of Sandhills Creek, indicates that the fold axis is subhorizontal. Outcrop relationships shown on Figure 2-1 indicate that in the Lower Sandhills Creek region the fold axis plunges gently north. $L_1^0$ lineations are affected by subsequent folding, as they display a wide variation in orientation. The use of this lineation as an indicator of fold axis trend and plunge is therefore limited.
Figure 3-4. Stereonet plots of poles to bedding attitudes from Shot Creek and the North Branch of Sandhills Creek.
(b) The NW-SE Trending Megascopic Fold Structure.

This structure was not recognised during field work but its presence was elucidated during stereographic and structural analysis of cleavage attitudes within the area. L₂ lineations plotted on Map 3 define a NW-SE axis of a possible fold structure in the Malones Creek area. The folding of slaty cleavage attitudes in this area (see slaty cleavage form line map Figure 3-5) confirms the presence of this fold. This synformal structure is definitely offset by the Coffey Creek Fault (see Map 3). The degree of offset and movement sense is consistent with that observed at localities in the Coffey Creek area. A structure of similar trend may also be present in the lower Little Slaty Creek region, however insufficient cleavage data was available to define this structure. If it is present, a continuation of this structure may in part explain the apparent swing in outcrop pattern of lithologies present in the Coffey's Creek area.

(4) Mesoscopic Folds

(a) North - South Trending Mesoscopic Folds.

Field mapping of lithologic contacts and bedding attitudes shown on Map 4 indicate the presence of a N-S trending generation of mesoscopic fold structures. These folds have short easterly limbs and often occur in pairs with a crest to crest distance of 30 to 90 metres. The mesoscopic folds appear to die out along the fold axis wherever it has been possible to trace them out completely. Field observations and stereonet plots
Figure 3-5  Slaty cleavage form line map.
Form line interval 80 metres. Axial traces of $F_2$
folds in black, $F_3$ folds in red.
Figure 3-6. N-S striking cleavage form line map.
Form line interval 80 metres.
indicate that the axial planes of megascopic folds strike N-S and are inclined steeply to the west. These fold structures plunge gently to the south and have NE-SW orientated axial plane traces. Figure 3-3 demonstrates that the attitude of an extensively developed N-S striking cleavage is parallel to the axial planes of the N-S trending mesoscopic folds as projected from bedding attitudes. This diagrammatic section also indicates that these mesoscopic folds post-date slaty cleavage formation. In the Malones Creek area the N-S striking cleavage maintains a relatively constant attitude (see Figure 3-6). This infers that N-S striking cleavage formation and N-S trending mesoscopic fold development post-dates the formation of the NW-SE trending megascopic fold structure.

(b) East - West Trending Mesoscopic Folds.

Anomalous bedding attitudes at several mine localities suggest the presence of weakly developed E-W trending mesoscopic fold structures. Maps (Figures 4-6 and 4-10) showing the bedding attitudes defining these folds are presented in Chapter IV. The E-W attitude of a weakly developed fracture cleavage, observed in the vicinity of the Aorangi Mine, suggests that it may represent a planar feature associated with this generation of folds. If this association is correct, then the attitude of this cleavage would suggest the mesoscopic folds' axial planes dip at moderate angles to the south and strike east-west. The disruption of form lines derived from
Plate 3-1  Photo and tracing of a Group-One minor fold. Note the tight axial angle and the undeformed nature of the sandstone beds.
N-S striking cleavage attitudes in the lower Little Slaty Creek area (see Figure 3-6) is possibly the result of these folds.

(5) Minor Folds

The rarity of minor folds within the Golden Blocks area prevented the use of overprinted fold relationships to determine the generation to which a minor fold belonged. Weathering of outcrops often made it impossible to determine the relationships of penetrative structures to individual minor folds. Thus, style and orientation were the two criteria used to divide minor folds into four groups. The style, orientation and distribution of folds in each of these groups is discussed below.

(a) Group One Minor Folds. Only two examples of this style of folding were observed; 1. Aorangi Mine Slip (627,543), 2. Malones Creek Ridge (618,549). These folds have tight axial angles and die out within three metres along the fold axis. The sandstone beds in plate 3-1 (minor fold from the slip at the Aorangi Mine) show little deformation in the hinge area while interbedded mudstones present in the same fold show considerable fracturing which prevents determination of cleavage relationships. However, slaty cleavage is clearly developed parallel to the axial plane of a minor fold observed on the Malones Creek ridge. Both minor folds show vergence directions the reverse of that
Figure 3-7  Attitudes of Group-Two minor folds. Poles to axial planes are represented by x. 0 represents the trend and plunge of the fold axis.

Plate 3-2  A Group-Two minor fold with an interlimb angle of approximately 90°. The synclinal axial plane is sheared.
required, if they are to be related to the Grand Sandhills Creek Anticline. This could be explained if the minor folds were the result of backsliding or similar movements during or after megascopic fold formation, the vergence directions reflecting the direction of movement rather than a relationship to the megascopic fold. The lack of fracturing of the sandstone beds folded by Group-One minor folds suggests that at the time of folding, the sandstone beds were more plastic or incompetent than the mudstone beds; (see plate 3-1) a situation which could only exist if the sandstone beds were partially lithified.

(b) Group-Two Minor Folds. Group-Two minor folds have tight axial angles with flat axial plane surfaces. The attitude of adjacent axial planes may diverge with respect to each other. The limb and hinge areas of folds show intense shearing and all folds have a distinctive steep plunge and verge north-east. The orientations of axial planes, trends and plunges of fold axes are shown in figure 3-7. All Group-Two minor folds are associated with shear zones.

(c) Group-Three Minor Folds. The axial planes of Group-Three minor folds strike N-S and fold axes plunge gently to moderately north and south as demonstrated in figure 3-8. These minor folds verge symmetrically about the axial traces of N-S trending mesoscopic folds. The N-S striking cleavage described previously is
Figure 3-8. Attitudes of Group-Three minor folds. See figure 3-7 for symbols definitions. Represented in this plot are the margins of point scattering of $L_2^O$ lineations derived from figure 3-13.

Figure 3-9. Attitudes of Group-Four minor folds. Symbols as for figure 3-7.
Plate 3-3  A Group-Two minor fold with an interlimb angle of 120°. Note curved axial plane surface.

Plate 3-4  Group-Two minor folds from the first level of the Anthill Mine.
developed parallel to the axial planes of many minor folds. As would be expected, the stereonet patterns obtained from plots of fold axes of Group-Three minor folds, are scattered in a similar manner to the butterfly shaped distribution obtained for plots of \( L_2^0 \) lineations.

All Group-Three minor folds have curved axial planes and die out within one to two metres along and perpendicular to the fold axis. The axial angles of these folds vary between gentle to open. Some Group-Three minor folds are asymmetrical, with one limb shortened and thickened (see plate 3-2). In other folds, shearing may occur along the axial plane or remove a portion of the shortened limb (see plate 3-3). At the Anthill Mine, Group-Three minor folds are present in a crush zone which occurs at the contact between Members AM\(_1\) and AM\(_2\) (see plate 3-4). At this locality Group-Three minor folds are also associated with shears parallel to bedding.

(d) **Group-Four Minor Folds.** Group-Four minor folds have close axial angles and the axial planes of these folds are generally curved. The characteristic feature of these folds is their association with crush zones of E-W striking faults, where they appear as hinge zones with sheared limbs. The symmetry of these folds is unknown. The minor folds die out within .3 to .5 metres along and perpendicular to the fold axis.
Figure 3-10. (a) Rose diagram of fault orientation.
(b) Contoured diagram of poles to faults. Contours at 2, 4 and 6%. A total of 64 points.
Group-Four minor folds have axial planes which dip at different angles although they consistently strike east-west. These folds trend between $110^\circ$-$145^\circ$ and plunge gently either to the east or west. The attitudes of axial planes and fold axes of these folds are shown in Figure 3-9.

(6) Faults and Shear Zones

Numerous faults with small displacements are present in the Golden Blocks area. The rose diagram, figure 3-10, indicates two dominant groups of fault and shear zone strikes in the area.

(a) N-S striking faults and shear zones,
(b) E-W striking faults.

(a) North-South Striking Faults and Shear Zones

Three generations of N-S striking faults and shear zones are recognised in the Golden Blocks area.

N-S striking shear zones which contain Group-Two minor folds occur in the Conn's Creek region (636,547) and at the Aorangi Mine (627,543). The Conn's Creek shear zone extends 400 metres along Slaty Creek and the lower reaches of Conn's Creek. This shear zone is up to 5 metres wide. A one metre wide shear zone containing Group-Two minor folds occurs at the contact of Member AM$_1$ and AM$_2$ exposed near the entrance to Number One Adit at the Aorangi Mine. Fifteen metres of this shear zone is exposed. The relationships of these two shear zones to
other structural events in the Golden Blocks area is unknown.

N-S striking faults with narrow well defined crush zones occur throughout the Golden Blocks area. This generation of N-S striking faults, termed Aorangi-type faults, dip to the west at angles varying between $30^\circ$ to $90^\circ$ (see figure 3-10(b)). Three N-S striking faults have outcrop relationships, see Map 4, which indicate 40 to 100 metres of sinistral movement. The results of field mapping indicate a small normal component of movement along the Anthill fault, while the Aorangi Fault has suffered a small reverse component of movement. Aorangi-type faults are often responsible for angular discordances observed at lithologic contacts and these faults are also an important lode controlling structure. The relationship of Aorangi-type faults to other structural elements in the Golden Blocks area could not be unequivocally determined from field relationships. However, it is reasonable to relate fault development to the same phase of deformation causing N-S trending mesoscopic fold formation because auriferous lodes are associated with the hinge zones of these folds.

Outcrop evidence at the Aorangi Mine (627,543) and the Slaty Creek gorge (627,561) indicates that E-W striking faults post-date second generation N-S striking fault movements. However, in the middle of Slaty Creek (638,552) and in an unnamed creek (640,549) the reverse
relationship was observed. Although fault development and movement is minor, this phase of faulting represents the third generation of N-S striking faults recognised in this area.

(b) **East - West Striking Faults.** E-W striking faults dip both south and north at angles varying between 30° and 90° (see figure 3-10(b)). Slickensides on E-W striking fault planes at the Aorangi Mine demonstrate the oblique - slip nature of movement along these faults and dextral slip movements of 20-40 metres are inferred from outcrop relationships. Normal slip movement is common. On the Coffey's Creek and Upper Coffey's Creek faults, normal slip offsets of 80 and 40 metres respectively were measured. The horizontal-slip movement components of these faults are unknown. E-W striking faults occur in zones with individual faults having wide crush zones. Faults present in the Coffey's Creek and Aorangi Mine areas are examples of two such fault zones (see Map 5). Group-Four minor folds are present in the crush zones of faults associated with the Coffey's Creek set and show similar axial plane attitudes. Quartz lodes are often associated with E-W striking faults. Multiple slickensides on quartz, developed in a fault plane at the Aorangi Mine, suggest several phases of movement.

Normal slip along the Upper Coffey's Creek Fault offsets Pakawau Beds by 40 metres, indicating a post-
Figure 3-11. A contoured equal area plot of poles to joints. Contours at 1%, 2% and 3%. Total number of points, 166.
Upper Cretaceous age for movement on this fault. The crush zone of this fault has no quartz veins developed in it and where E-W striking faults do have quartz veins developed in their crush zones they are considered to be pre-Upper Cretaceous in age.

(7) Joints

Joints are present in all lithologies but are especially well developed in thin and very thin bedded shale and fine sandstone units. Quartz filled joints are restricted to massive sandstone lithologies.

Joint information was not gathered by means of a systematic joint survey. The whole area was considered as a single domain with the bulk of the data coming from mine localities. Figure 3-11, a contoured equal area plot of poles to joints, shows a random joint distribution within the Golden Blocks area. Field evidence suggests that the majority of joints are related to faulting. Diagonal joints were associated with three minor folds but there is no evidence that jointing is related to folding on a regional scale.
3. STRUCTURAL SYNTHESIS

(1) Stereographic Analysis of Penetrative Planar and Linear Structures

Stereographic analysis of penetrative planar and linear structures was used to establish the sequence of folding events in the Golden Blocks area. Field evidence suggests that at least three generations of folding with associated cleavages, minor folds and lineations occur within the Golden Blocks area. Field relationships indicate that the slaty cleavage ($S_1$) is folded by mesoscopic folds to which the N-S striking cleavage ($S_2$) is the axial plane feature (see figure 3-3). Poles to this latter cleavage, plot as an approximate girdle distribution implying that this planar structure was refolded by subsequent tectonism. A poorly developed E-W striking fracture cleavage ($S_3$) was observed in the vicinity of the Aorangi Mine. This cleavage lies at a high angle to the fold and planar structures described earlier. If this cleavage post-dates these structures, and is associated with a phase of predominantly flexure-slip folding, then stereoplots of earlier planar and linear structures will be scattered in predictable patterns. Thus, assuming that the N-S trending folds are cylindrical with respect to the slaty cleavage, then the following should apply:

1. Poles to $S_3$ should plot as a point concentration, centred on the pole to the great circle which defines the
<table>
<thead>
<tr>
<th>Predicted Patterns from field relationships</th>
<th>Actual distributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial Plane of E-W Folds</td>
<td></td>
</tr>
<tr>
<td>Stereoplots of poles to $S_3$</td>
<td>A</td>
</tr>
<tr>
<td>Fold Axis of E-W Folds</td>
<td></td>
</tr>
<tr>
<td>Stereoplots of poles to $S_2$</td>
<td>B</td>
</tr>
<tr>
<td>Fold Axis of N-S Folds</td>
<td></td>
</tr>
<tr>
<td>Stereoplots of poles to $S_1$</td>
<td>C</td>
</tr>
</tbody>
</table>

**Figure 3-12.** A comparison of predicted and actual distribution of poles to planar structures from The Golden Blocks area.
axial plane of the flexure-slip folds.

2. In an ideal field situation, poles to $S_2$ are expected to be spread along a girdle pattern. The pole to this girdle pattern defines the fold axis of the flexure-slip folds. In the field situation observed at the Golden Blocks area, the attitudes of E-W trending folds are at a high angle to $S_2$. As a result, $S_2$ could not act as a suitable slip surface to the flexure-slip folding and it is expected that non-cylindrical folding will occur. This situation will cause scattering of points away from the ideal girdle distribution.

3. The poles to $S_1$ will be spread into a girdle pattern about the fold axis attitudes of the N-S trending mesoscopic folds and then further refolded to produce the characteristic butterfly pattern of twice folded surfaces. Predicted patterns of planar structures are shown in figure 3-12. The orientations and attitudes of fold structures and cleavage shown in stereoplots of predicted patterns were taken from field observations.

The approximate point concentration formed by the sparse measurements of the E-W cleavage ($S_3$) (figure 3-12(a)) defines an axial plane attitude for associated folds which strikes E-W and dips moderately to the south.
Stereonet plots of poles to $S_2$ do not match the predicted pattern (figure 3-12). Strong fanning of this cleavage about a mean N-S striking axial plane is observed in the field. This will result in variations in the cleavage attitude and cause points to be spread. As $S_2$ cleavages are folded by E-W striking flexure-slip folds, these points will be further scattered along E-W trending great circles, about the fold axis of these flexure-slip folds. This will result in a distribution similar to that observed in Figure 3-12(b).

Plots of poles to $S_1$, shown in figure 3-12(c), are widely scattered along an approximate girdle distribution although there are insufficient points to define a double-wedge shaped pattern.

Stereonet plots of all planar structures do not match predicted patterns (see figure 3-12). Apart from the reasons discussed above, other factors which may contribute to this non-match include

1. the fold structures are non-cylindrical
2. the presence of deformation events which are not directly observable in the field.

A further test of the sequence of deformation events derived from field evidence can be made by examining the stereographic distributions of linear structures. It may be predicted from the folding characteristics, that linear structures should behave in the following manner:
<table>
<thead>
<tr>
<th>Predicted patterns from field relationships</th>
<th>Actual distributions</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Predicted patterns" /> (Fold Axis of E-W Folds)</td>
<td><img src="image2" alt="Actual distributions" /></td>
</tr>
<tr>
<td>Stereoplots of $L_2^0$ lineations</td>
<td>A</td>
</tr>
<tr>
<td>Stereoplots of $L_2^0$ lineations</td>
<td>B</td>
</tr>
<tr>
<td>Stereoplots of $L_1^0$ lineations</td>
<td>C</td>
</tr>
</tbody>
</table>

Figure 3-13. A comparison of predicted and actual stereonet distributions of linear structures from The Golden Blocks area.
1. \( L_1^0 \) should be widely scattered.

2. \( L_2^1 \) should be spread initially along a great circle which defines the axial plane of N-S trending folding and then refolded into a butterfly distribution.

3. As the E-W striking folds are considered to be the result of flexure-slip folding, \( L_2^2 \) should be folded about an E-W trending small circle distribution, the centre of which defines the kinematic axis of folding.

Predicted patterns of linear structures are shown in figure 3-13(b) and (c).

Figure 3-13 indicates that patterns similar to those predicted were obtained for stereoplots of \( L_1^0 \) and \( L_2^0 \) lineations. The map distribution of \( L_2^0 \) lineations (Map 3) indicates a zone of East-West trending \( L_2^0 \) along the eastern bank of Sandhills Creek. These lineations differ strongly in orientation from the majority of \( L_2^0 \) lineations which trend north-south. This zone of anomalous lineation attitude results from the intersection of a steeply dipping cleavage with similarly dipping beds developed in the eastern hinge region of the Grand Sandhills Creek anticline.

The stereoplot of \( L_2^1 \) lineations, figure 3-13(a), does not form the expected paired small circle pattern nor does it define a great circle distribution which would
result if the fold mechanism was one of similar folding. On the basis of "plunge" $L_2^1$, lineations may be divided into two domains. Within the Malones Creek area these lineations define an axis which trends NW-SE. The non-match of predicted and observed stereonet patterns and the nature of the distribution and orientation of $L_2^1$ lineations provided the first suggestion of a fold structure previously unrecognised within the Golden Blocks area. This led to the analysis of cleavage attitudes by means of form lines (discussed previously, section 3-1(b)), which confirmed the presence of this fold structure, the formation of which predated $S_2$ development and postdated slaty cleavage formation. Assuming that the NW-SE trending fold structure is produced by a mechanism of similar folding, then it would be expected that $L_2^1$ lineations would lie on a girdle distribution resulting from the intersection of a curved surface ($S_1$) with a planar surface ($S_2$). Subjecting this distribution to refolding by E-W trending flexure-slip folds would rotate points away from the girdle distribution about east-west trending small circles. Such a pattern would be similar to figure 3-13(a).

Stereographic analysis of linear structures revealed the presence of a phase of deformation unrecognised by field studies. Analysis of cleavage attitudes indicated that the deformation phase was the
Table 3-1 A synthesis of structural events in the Golden Blocks area

<table>
<thead>
<tr>
<th>Structure</th>
<th>Deformation Phase Number</th>
<th>Relationship to Orogenic Events</th>
</tr>
</thead>
<tbody>
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<td>Slaty cleavage</td>
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<td></td>
</tr>
<tr>
<td>Grand Sandhills Creek megascopic fold</td>
<td>One</td>
<td>Pre-Tuhua Orogeny</td>
</tr>
<tr>
<td>Group-One minor folds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NW-SE trending megascopic fold</td>
<td>Two</td>
<td>?</td>
</tr>
<tr>
<td>N-S striking shear-zones</td>
<td>Three</td>
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<tr>
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<tr>
<td>N-S striking faults</td>
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<td>Post-weathering surface formation</td>
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<td>?</td>
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<tr>
<td>N-S striking faults</td>
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</tr>
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</table>
second folding event to affect the Golden Blocks area. The distribution of planar and linear structures was too scattered to determine the geometry of fold structures.

(2) **Deformation Phases in the Golden Blocks Area; A Description and Summary**

The relationships between structural elements elucidated from field studies and stereographic analysis are summarised in Table 3-1. In this table the number labelling each deformation phase refers to the timing of that phase relative to other deformation phases recognised in the Golden Blocks area. Also shown in Table 3-1 are the relationships of some deformation phases in this area to orogenic deformation events described from studies of other Nelson and Westland Paleozoic areas. These comparisons, which must be regarded as tentative, were made in an attempt to correlate structures controlling auriferous lodes in the Golden Blocks area with regional orogenic events. This latter aspect is discussed in Chapter IV section 10.

(a) **Deformation Phase One.** The field expression of Deformation Phase One is dominated by a megascopic fold, the Grand Sandhills Creek Anticline. Apart from the development of a slaty cleavage in mudstones throughout the Golden Blocks area, no other structures of consequence associated with this deformation
Figure 3-14. A summary of various authors' hypotheses as to the sedimentary, structural, igneous and metamorphic history of Nelson and Westland Paleozoic sediments.
phase were observed. The axial plane slaty cleavage associated with this fold has a low angular (0-10 degrees) relationship to bedding. This bedding-cleavage relationship, together with the small hinge zone and extensive overturning of strata, suggest that this fold, before subsequent tectonism, was a large scale recumbent fold.

Bishop (1968) and Grindley (1971 Takaka Sheet) described nappe-like folds and thrusts in rocks correlated with those in the Golden Blocks area. This is in contrast with the style of early deformation observed in this area.

Features exhibited by Group-One minor folds correlated with the Grand Sandhills Creek Anticline, suggest that deformation occurred while the sediments were partially lithified. Cooper and Duce (1975) reported similar "soft sediment" deformation in Lower Ordovician sediments at Mt Patriarch.

The interpretations made by Grindley (1961), (1971), Cooper (1975) and Shelley (1976) regarding the geological history of Nelson and Westland Paleozoic sediments are summarised in Figure 3-14. Grindley (1971) reported that the earliest regional deformation phase to effect sediments of the Aorere and Golden Bay Groups (Tuhua Orogeny) occurred during the lower Devonian to early Carboniferous. Studies by Adams et. al. (1975),
Cooper (1975) (see figure 3-14) and Shelley (1976) (see figure 3-14) suggest that sediments of the Greenland, Aorere and Golden Bay Groups were effected by an Upper Ordovician to Lower Silurian deformation event (Pre-Tuhua Orogeny). Deformation Phase One appears to have affected sediments of the Golden Blocks area, while they were still partially lithified. For this reason, this deformation phase is correlated with the Pre-Tuhua Orogeny, the earliest orogenic event known to affect Paleozoic sediments.

(b) **Deformation Phase Two.** Analysis of cleavage and stereographic data reveals the presence of a fold structure which predates N-S striking cleavage formation but which post-dates slaty cleavage development. This folding phase is weakly developed as shown by the apparent lack of planar structures and the poor field expression of this deformation structure. However, Deformation Phase Two fold structures may be responsible for low bedding attitudes in the Golden Ridge area (626,558 Map 2).

(c) **Deformation Phase Three.** The precise field relationships of two N-S striking shear zones observed in the Golden Blocks area to other structural elements of this area could not be determined. For convenience, this relatively minor deformation phase is recognised as Deformation Phase Three. N-S striking shear zones, which occur at or near lithologic contacts, are
considered to be the result of differential movement caused by deformation of lithologies of contrasting competency.

(d) **Deformation Phase Four.** A N-S striking cleavage folds structures belonging to Deformation Phases One and Two, and is itself folded by later tectonism. The cleavage forms parallel to the axial planes of well developed, steeply inclined, NE-SW trending mesoscopic folds which are observed throughout the Golden Blocks area. Stereographic analysis indicates that these structures formed by a mechanism of similar folding; the N-S striking cleavage acting as an axial plane slip surface.

At the Anthill Mine a number of symmetrical Group-Three minor folds are associated with shear and crush zones developed parallel to bedding. This suggests that the contact between Members AM\(_1\) and AM\(_2\), which are lithologies with contrasting competencies, may have acted as a partial décollement zone, with movement during folding expressed as shearing and crushing along the contact.

N-S striking faults with narrow, well developed crush zones and which are especially common at lithologic contacts, may be a further development of these shearing movements. Both N-S striking faults and mesoscopic folds of the same trend are lode
controlling structures (see Chapter IV section 3-10), and for this reason are considered to be related to the same deformation phase.

Deformation Phase Four is the best developed and most widely represented deformation phase observed in the Golden Blocks area. The style and orientation of the mesoscope folds belonging to this deformation event appear comparable to similar fold structures developed within sediments of the Aorere, Golden Bay, Haupiri and Mt Arthur Groups (Grindley (1971), Bishop (1971) and Cooper (1975)). Grindley (1971) (see figure 3-15) correlated these structures with Tuhua Orogenic events and a similar correlation is suggested for N-S trending mesoscopic fold and related structures in the Golden Blocks area.

(e) Deformation Phase Five. Moderate to steeply inclined fold structures associated with Deformation Phase Five are weakly developed, as demonstrated by poor field and stereographic expression. Stereographic analysis of lineations developed by the intersection of the N-S striking cleavage with bedding, suggests that E-W trending fold structures formed by a flexure-slip mechanism of folding. A dome structure, caused by the interference of this phase of fold structures with folds of Deformation Phase Four, is observed in the workings of the Golden Ridge Mine.
E-W striking faults are considered to belong to Deformation Phase Five because these faults offset structures associated with Deformation Phase Four. This is also supported by the observation that both E-W striking faults and folds of similar trend are lode controlling structures. E-W striking faults are common in the Golden Blocks area and appear to form a conjugate set pattern. As Deformation Phase Five structures are post-Tuhuan and do not fold or cut the Upper Cretaceous weathering surface, they are correlated with Rangitata Orogenic events.

(f) **Deformation Phase Six.** E-W striking folds which offset Pakawau Group sediments are of post-Upper Cretaceous age and are recognised as Deformation Phase Six. No quartz veins are associated with the crush zones of this minor phase of faulting. Some Deformation Phase Six fault movements have occurred along re-activated E-W striking faults related to Deformation Phase Five.
Figure 4-1  Geology of Aorangi Mine area.
Areas in the vicinity of mines were mapped at a scale of 1 cm = 40 metres. Mine plans showing productive areas were available only for the Aorangi Mine. Elsewhere stoped areas within the mines were used as guides to mineralized structures or lithologies. In this chapter sections 1 to 8 describe the geology of individual auriferous occurrences in the Golden Blocks area. Sections 9 and 10 summarise the structural, lithologic and stratigraphic associations of these occurrences.

1. THE AORANGI MINE (26,939 oz)

The stratigraphy and structure of the Aorangi Mine is shown in figure 4-1. Mineralized workings at the Aorangi Mine appear to be confined to the Mine Bed. Above the first Adit entrance, 42 metres of Mine Bed sandstones and mudstones are exposed while to the north the Mine Bed thins rapidly due to faulting. Pebble and granule size clasts of mudstones containing cream laminations with wedge-shaped terminations, a characteristic of Mine Bed mudstones, occur in small outcrops of
Figure 4-2. A diagrammatic plan view of the Aorangi Fault before offset movements by E-W striking faulting. The change in position of the fault plane with respect to the stratigraphic contacts of the Mine Bed is considered to result in an extensive crush zone, as shown. The letters refer to faults shown in figure 4-5. Dotted lines mark the future positions of two E-W striking faults.

<table>
<thead>
<tr>
<th>Stratigraphic units</th>
<th>Sediment texture and Stratification type</th>
<th>Crush zone and veining type 0 metres</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Member AM₁</td>
<td>Very thick sandstone</td>
<td></td>
<td>Mesh of thin veins in crush zone</td>
</tr>
<tr>
<td>Mine Bed</td>
<td>Thin to very thin bedded sandstone</td>
<td></td>
<td>Thin veins, also swells of quartz.</td>
</tr>
<tr>
<td></td>
<td>interbedded with thin to laminated mudstones</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Very thick sandstone</td>
<td></td>
<td>Mesh of thin veins</td>
</tr>
<tr>
<td>Member AM₂</td>
<td>Thin to laminated mudstones</td>
<td></td>
<td>Narrow smeared crush zone</td>
</tr>
</tbody>
</table>

Symbols
- Sandstone
- Mudstone
- Thin veins
- Thick veins

Figure 4-3. A diagrammatic representation of the effect of sediment competency on crush zone formation and veining types as observed for an E-W striking fault at the Aorangi Mine (Fault B in figure 4-5.)
sandstone in a slip above the first Adit entrance (Chapter II section 2-3).

In a 15 metre wide exposure near the first Adit entrance, a N-S striking shear zone containing Group-Two minor folds is observed. No quartz veins appear to be associated with this deformation phase.

A prominent structure at the Aorangi Mine is a N-S striking fault, the Aorangi Fault. This is one of several N-S striking faults in this area (see Fig. 4-1). Outcrop relationships indicate that small components of reverse and sinistral movement have occurred along the Aorangi fault. The fault plane dips west at angles ranging between 40-70°. In the northern workings of the Aorangi Mine, the Mine Bed is wedged out along this fault, the hanging wall being composed of the stratigraphically lowest portion of the Mine Bed. In a slip above the entrance to the first Adit is a fault zone which separates the stratigraphically highest portion of the Mine Bed from massive sandstone units of Member AM1. As the stratigraphically lower contact of the Mine Unit is not faulted, this may represent the southern extension of the Aorangi Fault. The position of the Aorangi Fault to the south of the slip is unknown. As illustrated in figure 4-2, the apparent change in the stratigraphic position of this fault may have resulted in an extensive crush zone. In other portions of the Aorangi fault, the crush zone is up to three metres wide. Thin quartz veins, up to 2
metres long, are scattered irregularly throughout this fault zone. Occurring at irregular intervals in the walls of drives which parallel the fault zone, are irregular and lensoid shaped masses of quartz up to 1 metre wide.

Numerous E-W striking faults occur at this locality. Slickensides on two separate fault planes indicate oblique dextral slip movements; the amount of movement is unknown. Several phases of movement along these faults are indicated by slickensided and brecciated quartz. Changing bedding attitudes between fault blocks indicates that rotational movements along E-W fault planes has occurred (see figure 4-1). The crush zones associated with these faults are narrow, (generally less than 1 metre wide) and contain scattered thin quartz veins up to 2 metres long. Swells of quartz up to one metre wide which contain numerous fragments of wall rock are occasionally observed. The effect of contrasting lithologic competencies on fault crush zone and vein development, is clearly illustrated (figure 4-3) by an E-W striking fault (fault c figure 4-5). In massive sandstone lithologies, the fault plane is marked by a zone of brecciation and veining up to 2 metres wide. In Member AM, mudstone beds are smeared along the fault plane and quartz veins are absent. Within the Mine Bed the fault plane is marked by a crush zone 3 to 1 metre wide with occasional
Figure 4-4. Mine Plan of the Aorangi Gold Mine.
Taken from Bell et al. (1907).
swells of quartz up to 1 metre wide. This competent response to deformation may result from the sandstone beds which are interbedded with mudstone lithotypes.

The gold mineralization at the Aorangi Mine was mined by means of four levels. Adit entrances to three of the four levels are shown in figure 4-1. The fourth level was reached from a shaft sunk below the Third Adit level. Mud and water partially fill the Third Adit making inspection of these levels impossible. Bell et al. (1907) who studied the Aorangi Mine before the commencement of work on the fourth level, found that the pay shoots follow a well defined course extending from the surface and gradually plunge to the south (see figure 4-4). Figure 4-5 is a three dimensional representation of the auriferous lodes in the Aorangi Mine, the distribution of which was derived from the mine plan of Bell et al. (1907). Depicted in this diagram are the relationships of stope areas to faults found by surface and underground mapping. In the northern portion of the mine workings, stoping appears to be confined to the Mine Bed where this unit is cut by the Aorangi Fault (labelled Fault A in figure 4-5). The richer portions of the auriferous lodes occur near the intersection of the Aorangi Fault with E-W striking faults B and C (see figure 4-5). E-W striking faults may cause increased fracturing within the Mine Bed, thus enhancing the permeability of the fractured portion of this unit.
Figure 4-5 The relationship of stope areas to faults at the Aorangi Gold Mine.
to hydrothermal solutions. Extensive stoping also appears to have occurred near the intersection of faults E and F. The lack of surface mining between faults B and C (figure 4-5) may be explained by down faulting of the Mine Bed along these faults. Fault F is interpreted; dense scrub precluded the mapping of the possible surface trace of this fault.

The richest portions of the lodes occur between outcrop and the first level and Bell et.al. (1907) suggest that supergene enrichment processes were responsible for producing these rich, near surface, ore values. Payshoots, although more limited in extent, occur down to at least the third level along fault intersections. Sediments in stope areas of these pay shoots are extensively weathered down to the Second Adit level (30 metres from the surface). Sediments in adit levels, away from the pay shoots occurring along fault planes and fault intersections, are usually unweathered. Thus fault zones appear to act as permeable zones for the movement of supergene solutions. Supergene enrichment processes may explain the occurrence of gold mineralization along the Aorangi Fault, a N-S striking fault, and along the intersections of this fault with younger E-W striking faults. Mine developments subsequent to the report of Bell et.al. (1907) encountered satisfactory values at depths 100 to 130 metres below surface outcrops and below present creek level. Such depths are below the possible
Figure 4-6  Geology of Anthill Mine area.
zone of supergene enrichment and may represent the primary ore tenor. The structures controlling stopen areas at these deep levels are unknown.

2. THE ANTHILL MINE (4,600 oz)

The geology of the Anthill Mine is shown in figure 4-6. The contact between Members AM₁ and AM₂ is extensively stopen in an irregular fashion and appears to have been the main area of production (see figures 4-7 and 4-8). In the vicinity of the Anthill Mine, the Mine Bed was only observed in a single outcrop in the sides of Anthill Creek (see figure 4-6). This unit is not present in Mine workings; probably being faulted out by reverse movement along the Anthill Fault.

A N-S striking fault, the Anthill Fault, occurs as a gently westward dipping crush zone in Anthill and Bottle Creeks and in mine workings. Group-Three Minor folds, with sheared limbs and hinge areas, commonly occur within Member AM₂ near its contact with Member AM₁. E-W trending mesoscopic folds were inferred from bedding attitudes observed in Little Slaty Creek and mine workings. Group-Four minor folds of similar trend were associated with low angle shears in mine workings.
Anthill Fault

---

- 1st Level
- 2nd Level
- 3rd Level

**Key**

<table>
<thead>
<tr>
<th>Lithologies</th>
<th>Symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Level</td>
<td>Faults</td>
</tr>
<tr>
<td>Drives</td>
<td>Drives</td>
</tr>
<tr>
<td>Member AM 2</td>
<td>Member AM 2</td>
</tr>
<tr>
<td>Member AM 1</td>
<td>Member AM 1</td>
</tr>
<tr>
<td>1st Level</td>
<td>Drives</td>
</tr>
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<td>2nd Level</td>
<td>Drives</td>
</tr>
<tr>
<td>3rd Level</td>
<td>Drives</td>
</tr>
<tr>
<td>Stoped areas</td>
<td>Stoped areas</td>
</tr>
</tbody>
</table>

Figure 4-7. A diagrammatic cross section of the Anthill Mine.

Figure 4-8. Plan of the Anthill Mine.
The mineralized zone at the Anthill Mine was mined from three levels. As shown in figures 4-7 and 4-8, the contact between Members AM$_1$ and AM$_2$ was extensively stoped between the first and second levels. The sediments in these stoped zones are extensively weathered. The third level was not studied as it is partially filled with mud and water.

Bell et al. (1907) reported that the majority of gold was won from weathered portions of the mine and that gold values decreased immediately on encountering unweathered carbonaceous sediments. This suggests that supergene processes were responsible for enhancing primary gold values. Thick and thin quartz veins, up to 2 metres long, occur sparsely in the walls of stoped areas. Lensoid and irregular shaped masses of quartz are also observed. Veins are either developed parallel to bedding or associated with shear zones. It is difficult to determine from field evidence which structural event was responsible for shearing along this contact. Possible explanations are as follows:

1. Deflection of reverse movement on the Anthill Fault along the lithologic contact.

2. Shearing resulting from the development of a décollement zone between Members AM$_1$ and AM$_2$, lithotypes of contrasting competences, during N-S trending folding.

3. Shearing resulting during development of a similar type of décollement zone during E-W trending
Figure 4-9 Plan and geology of the Fault Adits Mine area.

Figure 4-11 Plan of the upper level of the Golden Ridge Mine.
folding.

Irregularly shaped stope zones below this contact are possibly associated with the fold axis of the E-W trending mesoscopic fold.

3. THE FAULT ADITS MINE (50 oz?)

The Fault Adits Mine is located in the upper reaches of Anthill Creek and its stratigraphic position is within Member AM₁. At this mine a thinly bedded carbonaceous mudstone, approximately ten metres thick, and a massive sandstone unit are juxtaposed along a N-S striking fault as shown in figure 4-9. To the north and south of the Fault Adits Mine, litharenites and sub-litharenites containing volcanic rock fragments, occur at a similar stratigraphic level as the carbonaceous mudstone observed in mine workings. A small outcrop of Upper Cretaceous sediments occurs to the south-east of this mine. Along the fault plane exposed at the Fault Adits Mine, Paleozoic mudstones are extremely leached and weathered. The mineralized zone at this mine, a lenticular body of quartz (Bell et al. (1907)), was exploited by means of two drives and a shaft.

4. THE GOLDEN RIDGE MINE (4,500 oz)

Outcrop in the vicinity of the Golden Ridge mine is poor and much of the geology (figure 4-10) is interpreted from small isolated exposures. Mineralized
Figure 4-10. Geology of Golden Ridge area.
areas appear to be confined to the Mine Bed, which is approximately 20 metres thick in the vicinity of this mine.

The two upper most levels of the Golden Ridge mine were accessible while the lower most level, driven in sandstones of Member AM₁, was filled with water. Mapping of bedding attitudes in the upper levels of the mine (see figure 4-11) defined a dome-shaped structure. The vergence directions of Group-Three minor folds and bedding attitudes in mine workings and in the surrounding area, suggested that this structure was the result of interference between N-S and E-W trending mesoscopic folds.

Irregular and lensoid shaped veins are associated with crush zones in the Mine Bed mudstones, which are also extensively weathered. Bell et.al. (1907) reported that the richest portion of the mineralized zone was roughly annular in shape and surrounded a dome structure.

5. THE NEW FIND MINE (2,000 oz)

The geology of the New Find Mine is shown in figure 4-10. Although exposure in the vicinity of the mine is very poor, the mineralized zone appears to be confined to the Mine Bed. This interpretation is supported by a study of Bell et.al. (1907). Upper Cretaceous coal measures and conglomerates outcrop to the north of the New Find Mine (see figure 4-10).
The outcrop pattern in the vicinity of the mine is interpreted to be the result of N-S striking mesoscopic folding and E-W striking faulting. Bell et al. (1907) reported that the structure at the New Find Mine consisted of

"A minor anticline on the major synclinal limb pitching (plunging) slightly to the south, gives rise on each side of its axis to shallow synclinal troughs in the bedded system. These, when viewed in plan, present a fork-shaped outline and it was from these troughs that the more highly enriched portion of the vein material was extracted."

Bell et al. (1907), pg 93.

The collapse of adits at this mine prevented examination of the mineralized zone, however, surface outcrops and mine tailings suggest paleozoic sediments were extensively weathered at this locality.

6. THE MORNING STAR AND OLD GOLDEN RIDGE MINES (6,000 oz)

At the Morning Star Mine, mine workings occur within mudstone sediments of Member AM3 near its contact with massive sandstones of Member AM4, as shown in figure 4-10. Upper Cretaceous mudstones outcrop immediately above the mine workings (see figure 4-10). Sediments in the vicinity of this mine are folded by a N-S trending mesoscopic fold (see figure 4-10). Faulting near the mine is complex. A number of adits appear to intersect a N-S striking fault which has a
sinistral movement component. To the north, this fault is terminated by E-W striking faults of the Coffey Creek fault system. The mineralized zone at the Morning Star Mine was mined via three levels. The condition of adits rendered inspection impossible. Vein samples from mine tips contain numerous host rock inclusions and accumulations of carbonaceous material. Mine tailings from even the upper-most levels of this mine appear unweathered.

Mine workings of the Old Golden Ridge Mine are confined to Member AM$_3$, near its contact with Member AM$_4$; a stratigraphic position similar to that of the Morning Star Mine. Upper Cretaceous coal measures, mudstones and conglomerates, unconformably overlie weathered Paleozoic sediments at the Old Golden Ridge Mine. Mine workings have collapsed and outcrop expression is very poor. Sparse bedding attitudes suggest the presence of E-W trending mesoscopic folds near this mine. Park (1890) reported that auriferous quartz veins at the Old Golden Ridge Mine were confined to a narrow band of sheared mudstone.

7. AURIFEROUS LODES IN THE MALONES CREEK REGION (50 oz?)

Several small auriferous lodes were found along the southern headwaters of Malones Creek at Tinnes and Maori Gullies (615,553), (613,555). These claims occur within the upper portions of the Sandhills Creek Formation.
Scattered outcrops of basal Upper Cretaceous conglomerates occur throughout the area. No economic auriferous lodes were located in spite of intensive prospecting (i.e. the Great Northern prospecting drive) and the presence of rich alluvial finds in this area.

8. THE FRIDAY CREEK MINE (800 oz)

Workings at the Friday Creek Mine are confined to the lower portions of the Sandhills Creek Formation, which is predominantly composed of sublitharenites and litharenites containing rock fragments of possible volcanic origin. Upper Cretaceous to Tertiary sediments, outcrop 300 metres to the north of this mine and Paleozoic sediments at the mine are extensively weathered. The lack of outcrop and collapsing of mine adits made interpretation of the structure at this mine impossible. Bell et al. (1907) reported that work at this mine ceased when the auriferous zone was lost in a slip.

9. THE STRATIGRAPHIC AND LITHOLOGIC ASSOCIATIONS OF AURIFEROUS OCCURRENCES IN THE GOLDEN BLOCKS AREA

All auriferous occurrences are associated with quartz lodes in Paleozoic sediments. However, studies of mineralized zones in the Golden Blocks area indicate that supergene processes associated with the Upper Cretaceous weathering surface possibly influence the
Figure 4-12 Lithologic and stratigraphic relationships of auriferous lodes in the Golden Blocks area.
distribution and economic potential of gold deposits in this area. This aspect of the gold mineralization is discussed in Chapter VII; Supergene Enrichment.

The stratigraphic positions of auriferous lodes in The Golden Blocks area are shown in figure 4-12. Bell et al. (1907) considered that the stratigraphic position of mineralized zones were

"Definitely confined to a narrow band of carbonaceous sometimes siliceous, argillite which has been referred to as never exceeding 20ft in width."

Bell et al. (1907) pg 90.

This lithologic unit was recognised in the field by the author and assigned a formal name; the Mine Bed. Mapping confirmed that mineralized zones at the Aorangi, Golden Ridge and New Find Mines occur within the Mine Bed. However, mapping by the author has shown that the stratigraphic position of three important mines, the Anthill, the Old Golden Ridge and Morning Star Mines do not lie within the Mine Bed, nor do other smaller auriferous occurrences. The mineralized zone at the Anthill Mine occurs at the contact of Members AM₁ and AM₂, while the Morning Star and Old Golden Ridge Mines occur within Member AM₃ near its contact with Member AM₄. The Fault Adits Mine occurs within Member AM₁. The stratigraphic positions of the Friday Creek Mine and the lodes at Tinnes Creek are within the Sandhills Creek
Formation. Although major gold producing mines are associated with specific stratigraphic horizons or beds, minor auriferous occurrences are scattered throughout particular stratigraphic units.

Table 4-1 Age of mineralized units in Golden Blocks Area.

<table>
<thead>
<tr>
<th>MINE</th>
<th>PRODUCTION IN OZ</th>
<th>AGE *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friday Creek</td>
<td>800</td>
<td>Pre to Mid</td>
</tr>
<tr>
<td>Tinnes Creek lodes</td>
<td>?50</td>
<td>Lancefieldian</td>
</tr>
<tr>
<td>Fault Adits</td>
<td>?50</td>
<td></td>
</tr>
<tr>
<td>Aorangi</td>
<td>27,000</td>
<td>Mid-Upper</td>
</tr>
<tr>
<td>Golden Ridge</td>
<td>5,400</td>
<td>Lancefieldian</td>
</tr>
<tr>
<td>New Find</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td>Anthill</td>
<td>4,600</td>
<td></td>
</tr>
<tr>
<td>Morning Star</td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>Old Golden Ridge</td>
<td>6,000</td>
<td>Yapeenian</td>
</tr>
</tbody>
</table>

* Ages determined by Cooper (1967), (1975).

The approximate ages of mineralised stratigraphic units are summarised in Table 4-1. The largest production of gold in the Golden Blocks area is derived from sediments of Lancefieldian age.
The composition of stratigraphic units in the Golden Blocks area and their relationships to auriferous occurrences is shown in figure 4-12. Poor exposure at the Friday Creek Mine and at Malones Creek lodes prevented the precise determination of the lithologic associations of these minor occurrences in the Sandhills Creek Formation. However sandstones composed of sublitharenites and litharenites containing possible volcanic rock fragments and mudstones are observed in the vicinity of both occurrences. A minor auriferous occurrence, the Fault Adits Mine, is associated with a mudstone unit near the top of Member AM₁. To the north and south of this mudstone unit, at about the same stratigraphic level, are litharenites and sublitharenites of similar composition to those observed near auriferous lodes in the Sandhills Creek Formation. All of the productive mines in the Golden Blocks area are confined to carbonaceous mudstones near the contacts of thick sequences of sandstones and mudstones. Eighty-five percent of the gold production of this area comes from mines associated with mudstones of the Mine Bed and Member AM₂ near its contact with Member AM₁.

10. STRUCTURAL ASSOCIATIONS OF AURIFEROUS OCCURRENCES IN THE GOLDEN BLOCKS AREA

Mapping of mineralized zones in the Golden Blocks area indicates that the distribution of auriferous quartz veins is strongly controlled by structural features. A
description of the quartz veins and the processes of vein formation in the Golden Blocks area is discussed in Chapters V and VI. Structures controlling the distribution of stoped areas at various mineralized localities are summarised in Table 4-2.

Table 4-2 Lode Controlling Structures

<table>
<thead>
<tr>
<th>Mine</th>
<th>Production (in oz)</th>
<th>Possible Lode Controlling Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aorangi</td>
<td>26,939</td>
<td>N-S and E-W striking faults</td>
</tr>
<tr>
<td>Anthill</td>
<td>4,600</td>
<td>Crush zones formed by either 1. N-S striking faulting, or 2. possible movement along décollement zones during (a) N-S trending folding, (b) E-W trending folding.</td>
</tr>
<tr>
<td>Golden Ridge</td>
<td>5,400</td>
<td>Irregular crush zones round a dome shaped structure; possibly caused by the interference of N-S and E-W striking folding.</td>
</tr>
<tr>
<td>New Find</td>
<td>2,000</td>
<td>N-S trending folding.</td>
</tr>
<tr>
<td>Morning Star)</td>
<td></td>
<td>N-S striking faulting</td>
</tr>
<tr>
<td>Old Golden Ridge</td>
<td>6,000</td>
<td>E-W striking folding</td>
</tr>
<tr>
<td>Fault Adits</td>
<td>? 50</td>
<td>N-S striking faulting</td>
</tr>
<tr>
<td>Friday Creek</td>
<td>800</td>
<td>Unknown</td>
</tr>
<tr>
<td>Tinnes Creek area</td>
<td>? 750</td>
<td>Unknown</td>
</tr>
</tbody>
</table>
Structures associated with Deformation Phases Four and Five control the distribution of quartz lodes and veins at mine localities. In this thesis these deformation phases are correlated with Tuhua and Rangitata Orogenies respectively. At the Morning Star and Fault Adits Mines, stoped areas appear to be confined solely to N-S striking fault zones (Deformation Phase Four). At the Aorangi, Anthill and Golden Ridge Mines the mineralized zones are often associated with the intersections of structures belonging to Deformation Phases Four and Five. It is inferred from the above relationships that lode distribution is controlled by structures of Deformation Phase Four. The association of mineralized zones with the intersections of structures belonging to Deformation Phase Four and Five may be the result of the enhanced permeability of these intersections to supergene solution movement and enrichment.
Figure 5-1. Vein size distributions.

(a) Combined measurements from all lithologies
(b) Vein size distribution in sandstones
(c) Vein size distribution in mudstones
VEIN MORPHOLOGY AND THICKNESS

The thickness of quartz veins in the Golden Blocks area is shown in Figure 5-1. Sediment texture has an important effect on the morphology and frequency of vein occurrences in the Golden Blocks area. Sandstones in this area usually contain numerous quartz veins compared with mudstones. Veins which are less than 50 mm wide, and are linear features 5-15 metres in extent, represent the most commonly observed vein type in sandstone lithologies. Such veins commonly parallel joint sets, especially in very thick sandstone lithologies. Veins in sandstones are less frequently observed as a swarm or mesh of linked veins, see Figure 5-2. Sheeted occurrences of veins (see Figure 5-2) are occasionally observed. Linked or sheeted veins generally occur as vein swarms up to 5 metres wide and are invariably continuous over the outcrop (5-20 metres). These veins contain numerous host-rock inclusions (see Chapter VI section 1-4(d)). Most veins in sandstones which are more than 150 mm in thickness are linear features, and are continuous over an exposure (5-20 metres). These
(a) linear veins.

(b) lensoid veins.

(c) sheeted veins.

(d) linked veins.

Figure 5-2 Vein morphology.
Veins may terminate in, or be associated with, sheeted or linked veins.

When compared with veins in sandstones, mudstone lithotypes contain fewer and less continuous veins. The most commonly observed vein type in mudstones are veins which are less than 50 mm wide and are linear features extending for 2 to 3 metres. These veins often form parallel to bedding. Irregular and lensoid-shaped veins are frequently observed. Quartz veins in deformation zones which intersect mudstones, generally consist of a scattered series of discontinuous (2-3 metres long), thin (less than 50 mm wide), linear veins. At the Aorangi Mine (628,542) and workings near Bottle Creek (627,548), quartz lodes up to 1 metre wide are occasionally observed. These veins which are associated with fault zones and contain numerous host-rock inclusions are linear and continuous over the extent of exposures in mine workings (5-10 metres). Detailed descriptions of vein occurrences in mudstone lithologies at mine localities are given in Chapter IV sections 1-8.

II VEIN PETROLOGY AND MINERALOGY

(1) Quartz

Quartz forms the dominant constituent of most veins and wide variations in both size and shape of the constituent quartz grains is observed. Grain size ranges from 7.5mm to 0.015mm.
Plate 5-1  Illustrated are thin deformation bands containing fluid inclusions. These bands are continuous across crystallographic boundaries. Cutting deformation bands at high angles on the right hand side of this photomicrograph are inclusion free bands of unknown origin. (U.C. 8001) Crossed-polarised light.

Plate 5-2  Discontinuous deformation lamellae (U.C. 8001) Crossed-polarised light.
Primary growth textures are exhibited in many veins. Frequently vugs and comb structures and other growth textures are outlined by variations in fluid inclusion densities. Quartz grains in such veins generally have straight extinction and sharp angular margins.

Quartz crystals with sutured margins and undulatory extinction indicate that many veins have suffered slight recrystalization, which may be the result of later deformation. Large quartz grains (more than 0.3 mm width) are especially affected, while associated small grains (less than 0.3 mm width) usually only display shadowy extinction. In such large grains deformation bands, discontinuous and continuous deformation lamellae were observed (Spry 1968). Under high magnifications (x1100) continuous deformation lamellae are seen to be narrow planes containing numerous fluid inclusions. Some discontinuous deformation lamellae are very thin deformation bands (see plate 5-1). Depicted in plate 5-2 are inclusion free discontinuous deformation lamellae. These lamellae are due to dislocations of the quartz grain lattice, a result of stress (Fairbairn 1941, Tuttle 1949, Turner and Weiss 1963, Carter and Friedman 1965). Veins containing the features discussed above are often cut by thin elongate zones filled with microcrystalline quartz. The quartz in these zones is often accompanied by graphite,
carbonates and solid inclusions of micaeous minerals. Quartz grains in most veins contain numerous fluid inclusions, in particular, secondary inclusions. The abundance of fluid inclusions gives the quartz a turbid appearance. Large veins are often cut by veinlets of inclusion - poor quartz (phantom veinlets). The lack of fluid inclusions, common in veins formed from hydrothermal fluids, suggest that phantom veinlets are the result of recrystallization processes.

(2) Carbonates

Dolomite and siderite are common constituents of many veins and were identified by x-ray diffraction and optical techniques. Ankerite occurs sparsely. These carbonates occur as irregular masses between 5 to 0.4mm in length. Replacement textures are common. Inclusions of both siderite and dolomite up to 0.04mm occur infrequently within quartz grains. The carbonates are not restricted to a single phase of vein formation, although they are especially common in micro-veinlets which cut larger veins.

(3) Micas

Muscovite, sericite and chlorite are common minor constituents of quartz veins, especially those which contain carbonaceous material or host-rock inclusions. Sericite is more frequently observed than chlorite or muscovite. When associated with carbonaceous material the micas occur as small flakes less than 0.03mm long.
These micas are also commonly observed at the margins of quartz grains or as inclusions within the grains. Host-rock inclusions within veins contain sericite as a major constituent.

(4) **Carbonaceous Material**

Carbonaceous material is confined to veins cutting carbonaceous sediments. Landis (1971), suggested a four-fold division of subgraphitic carbonaceous material based on the degree of ordering of the graphitic lattice. X-ray diffraction of carbonaceous material from both veins and surrounding sediments indicate this material to be virtually amorphous; corresponding in Landis's classification to graphite-3d. The shape and size of carbonaceous material is extremely variable. Long "wisps" of this material form particularly distinctive shapes. The nature and origin of such material is described and discussed in Chapter VI section 4-3(a).

(5) **Dickite**

Dickite occurs sparsely as euhedral crystals or irregular masses in veins associated with mudstone sediments. Dickite filled fractures were also observed. This clay mineral is a common product of hydrothermal alteration by acid solutions (Deer, Howie and Zussman (1962)).
(6) **Host-Rock Inclusions**

Numerous veins contain fragments of sediments, similar in composition to that of vein host rocks. Many terms, such as sediment relics or inclusions have been used to describe such structures. In this thesis, the term "host-rock inclusion" is used. This is defined as a fragment, similar in composition and texture to host-rock sediments, which is partially or wholly surrounded by vein material. These inclusions range in length from 0.02mm to 70 mm and are extremely variable in shape, especially those inclusions in veins cutting mudstones. Linked and sheeted veins cutting sandstones may contain distinctive slab-shaped inclusions, the long axes of which are parallel to vein walls. The possible modes of formation of such fragments are discussed in Chapter VI section 1-4(d).

(7) **Sulphides**

In vein quartz, pyrite occurs as small euhedral and irregular shaped masses which range between 20mm and 0.002mm in diameter. Pyritic veins often contain dolomite. Polished sections revealed that more pyrite occurs in vein-wall rocks, host-rock inclusions and carbonaceous matter within the vein than is found in vein quartz. Two types of pyrite occur within sedimentary components;

1. euhedral and irregular shaped pyrite and
2. frambooidal pyrite, which Love (1962)
attributes to formation by bacterial processes. The source of the former type of pyrite could not be determined. Indirect evidence from studies of arsenopyrite (discussed below) suggests that the euhedral pyrite possibly originates from vein solutions.

In samples from the Great Northern Prospecting Drive, (grid reference 614554) arsenopyrite and dolomite was observed in vein quartz. Arsenopyrite also replaced constituents of vein host-rocks, a carbonaceous quartz arenite. No framboidal arsenopyrite was observed in vein wall-rocks and it is suggested that the arsenopyrite originated from vein solutions. Small irregular and euhedral masses of arsenopyrite are associated with pyrite in a carbonaceous, micaceous clay lutite adjacent to a vein in the middle reaches of Big Slaty Creek (grid reference 633555). This vein contained dolomite and sphalerite.

Eugster and Skippen (1967), suggest that carbonaceous material, a common minor sedimentary constituent, may affect the fugacity of vein or mineralizing components, thus influencing the deposition of minerals from vein solutions. The association of arsenopyrite and pyrite with vein-wall rocks and sedimentary constituents within the vein suggest that the chemical character of sedimentary components may influence the deposition of these sulphides from vein solutions.
Small irregular shaped masses of marcasite were identified in polished sections of quartz veins from the Anthill and Morning Star Mines. Pyrite pseudomorphs of marcasite are frequently observed. Such pseudomorphs are also associated with pyrite in some veins. Examples of simultaneous deposition of both marcasite and pyrite have been observed (Ramdohr, 1969). The chemical conditions present during deposition are unknown. Bell et al. (1907), reported that small quantities of marcasite often accompanied auriferous quartz lodes.

Galena was identified in a float sample from Sandhills Creek. The galena replaced pyrite; both of which are replaced by hematite.

Ongley and McPherson (1923) found pyrite and traces of molybdenite and galena in quartz veins and aplitic dykes associated with granite at Knuckle Hill which outcrops 7 miles to the east of the Golden Blocks area. Field work by the author confirmed the presence of pyrite at Knuckle Hill.

(8) Gold

Bell et al. (1907) recognised three modes of gold occurrence,
1. as films on fracture or cleavage surfaces,
2. as well defined streaks parallel to the crushed margins of veins,
3. dotted throughout a mass of brecciated quartz
in close association with graphitic inclusions. Small (4mm to 0.02mm in diameter), irregular shaped flakes of gold, associated with limonite stained fractures were found in a sample of quartz vein from the ore dump of the Taitapu Battery (grid reference 619567). In a vein sample from the Aorangi Mine (grid reference 628543) gold was observed within vein quartz.

(9) Azurite and Limonite

Azurite blooms were associated with weathered quartz veins in the adits of the Aorangi and Anthill Mines. Weathering did not allow identification of the original copper mineral. Liminitic stained fractures and vugs are particularly common in quartz veins in weathered sediments. The limonite is undoubtedly produced by the weathering of sulphides present in the veins.

III VEIN GEOTHERMOMETRY

(1) The Mineralogy of Vein Constituents and Wall Rocks; A guide to Vein Temperatures

The presence or absence of key minerals, normally used in metamorphic petrology as temperature and pressure indicators was used to set limits on temperature conditions within quartz veins of the Golden Blocks area.
Muscovite occurs as large flakes (0.5 mm in length) in many quartz veins and associated host-rock inclusions. Sericite is also very common. Biotite is absent in host-rock inclusions and quartz veins. Under conditions existing during classic Barrovian-type metamorphism, biotite forms above 420°C (1-4 K bars) (Winkler, 1971). Assuming that the chemical conditions are suitable for the formation of biotite in the veins of this area, a situation which appears probable considering the hydrothermal character of the vein system, then the absence of biotite suggests that vein formational temperatures did not attain 420°C. The lack of extensive wall-rock alteration is an interesting feature of veins in the Golden Blocks area. This may be explained by either the lack of reactive wall-rock constituents or by vein-forming solutions which are in partial or complete thermal equilibrium with vein host-rocks.

(2) Fluid Inclusion Studies

Fluid inclusions represent small portions of fluids trapped within mineral grains. When selecting inclusions for study, it is necessary to pick primary inclusions as these represent portions of the original vein-forming fluids; secondary inclusions are formed subsequent to vein formation. In the Golden Blocks area primary inclusions are rarely larger than 10 μ wide; usual diameters are in the order of 3-5 μ. Secondary inclusions are usually 3 μ or less. Fluid inclusions
in the Golden Blocks area are extremely small when compared with inclusions used by other authors (e.g. Roeder (1971)) for filling temperature determination, and magnifications in the order of 1100 times are necessary when viewing these inclusions. Thus determination of homogenization and freezing temperatures demanded particular care and patience. Planes of secondary inclusions are extremely common, in some samples (veins from Top Creek, Anthill Mine, Bush Track and Baldy:- for grid references see Table 5-1) secondary inclusions are so numerous that positive identifications of primary inclusions could not be made. Roeder (1971) reported numerous planes of secondary inclusions in veins from the Bingham district, the formation of which he attributed to repeated fracturing under hydrothermal conditions. Primary inclusions, which are suitable for experimental purposes occur sparsely and are usually found in euhedral crystals containing few secondary inclusions. Such crystals are frequently found in vugs within a vein. Negative crystal shapes and tubular shaped inclusions are rare.

If vein formational or trapping temperatures are to be obtained using fluid inclusions, it is necessary to measure or estimate the following:
1. The filling or homogenization temperature of the inclusion.
2. Salinity of the inclusion fluids.
3. The load pressures to which the inclusion is subjected at the time of formation.
(a) **Filling Temperature Determination.** The temperature at which fluid and gas phases are in equilibrium at atmospheric pressure, marked by the disappearance of a gas bubble, is termed the filling temperature. The filling temperature of an inclusion may be measured using a heating stage (see appendix I). The results of filling temperature determinations on both primary and secondary inclusions in veins collected from throughout the Golden Blocks area is shown in Table 5-1. Filling temperatures of primary inclusions range between $316^\circ - 200^\circ C$ and this variation is the subject of discussion in section (d).

(b) **Inclusion Fluid Salinity Determinations.**
It is known (Le mmlein et.al. 1961, Souirajan et.al. (1962)) that the salinity of inclusion fluids markedly effects the vapour pressure of fluid phases in an inclusion. Thus, a correction for this factor must be considered when determining the trapping temperature of an inclusion. The freezing stage and procedures used to measure inclusion fluid salinities are described in appendix II. Four cooling runs were made using two samples of quartz veins collected from the middle of Big Slaty Creek (634,565), and the top of Big Slaty Creek (620,540). The contents of a large inclusion completely froze at $-35.4^\circ C$. The phenomenon observed represents the first melting temperature of an inclusion (Roeder, 1962) and because of poor light conditions, a
result of freezing stage construction, the freezing point temperature of the inclusion could not be observed on heating.

This fluid inclusion was the only one observed to freeze. A metastability phenomenon, possibly due to the small size of inclusions may have prevented other inclusions in this sample from freezing. Super-cooling of specimens was attempted by placing them in liquid nitrogen for short periods. However, problems concerning the breaking of specimens and the relocation of the inclusion prevented use of this method. However, the lack of daughter salts in fluid inclusions of the Golden Blocks area, suggest that inclusion fluid salinities do not exceed 23% Na Cl (Röder (1963)).

A multi-phase inclusion containing a second liquid (probably carbon-dioxide) was observed on cooling a quartz vein sample from Slaty Creek (634,565). This vein contained dolomite. The effect of gases, other than water vapour, on the filling temperature correction is an additional factor which should be allowed for when determining the trapping temperature (N. Newman, personal communication). A correction for this factor was not considered.

(c) Load Pressure Estimation. The thickness of rock above the site of vein and fluid inclusion formation subjects the contents of an inclusion to a load pressure.
To obtain the trapping temperature of a fluid inclusion, it is necessary to add a correction factor for the load pressure to the filling temperature because the filling temperature of an inclusion is measured at atmospheric pressure. It is not practical to estimate the load pressure due to sediment thickness in the Golden Blocks area, because of the development of a major unconformity prior to vein formation. If boiling of vein fluids occurs during inclusion formation then pressure correction is not required as the vapour pressure of the fluid will equal the load pressure. Large gas bubbles are observed in some fluid inclusions if vein fluids boil (Roedér (1971)). However, such inclusions are not observed in veins of the Golden Blocks area.

An upper limit on the value of a correction factor may be estimated for veins of the Golden Blocks area using the maximum temperatures of vein formation obtained from studies of vein micas. The absence of hydrothermal biotite suggests that during vein formation temperatures did not exceed 420°C (1-5 K bars). The highest filling temperature of inclusions from this area was 316°C for a vein from Conical Hill (Grid reference 622,550). Thus using the above method, the maximum correction factor which may be applied to veins of this area is 104°C. If a correction value is known, it is possible to determine the load pressure to which inclusions were subjected by using tables prepared by Le mmlein et.al. (1961). A load
Table 5-1 Vein homogenization temperatures

LOCATION (grid reference)

Conical Hill (622550)
Mid. of Sandhills' Ck. (609557)
Mid. of Big Slaty Ck. (634565)
Old Golden Ridge Mine (627566)
Aorangi Mine 1st Vein (627556)
Aorangi Mine 2nd Vein (627556)
Morning Star Mine (629560)
Fault Adits (625559)
Nth Br. Sandhills Ck. (618532)
Gt. Nth Extended (615533)
Aorangi Mine (627566)
New Find Mine (626556)
Top of Big Slaty Ck. (640530)
Top of Shot Ck. (620540)
Top Ck. (641540)
Anthill Mine (627551)
Bush Track (641561)
Baldy (624567)
pressure of 1.1 Kbars (± 100 bars), allowing for the salinity of inclusion fluids being 0-23% NaCl was obtained using these tables. A load pressure of this value suggests a maximum depth of vein formation for veins in the Golden Blocks area of 3.6 kms.

(d) Interpretation of Filling Temperature Results. The results of filling temperature determinations of inclusions in veins of the Golden Blocks area is shown in Table 5-1. Variations in the filling temperatures of primary inclusions range between 2°C - 16°C (average range 7°C). The paucity of data for any individual vein means that the range observed only represents the minimum degree of variation. Only part of such ranges can be explained by experimental errors; experimental errors are ± 5 degrees (see appendix I). For example, primary inclusion filling temperatures within a vein from the top of Big Slaty Creek (640,538) show a range of 16°C; a greater range than could reasonably be explained by experimental errors. Thus, the ranges of primary inclusion filling temperatures shown in Table 5-1 may represent an actual range of filling temperatures within some veins. Changes in trapping temperatures do not necessarily result in a range of filling temperatures. Variations in either the pressure at the time of trapping or the salinity of vein fluids, or both, may account for ranges in filling temperatures within a vein. Several aspects concerning vein formation may explain intra-vein variations in filling temperatures.
1. Composite veins, which are composed of several generations of quartz are common in the Golden Blocks (see Chapter VI Section 1-4(d)). Conditions may easily differ for the formation of each phase of quartz.

2. Abrupt pressure changes occur during fracturing. The filling temperatures of inclusions formed during such pressure changes may differ from those formed at other periods of vein formation.

3. Pressure changes caused by choking of fluid passageways or by tectonic events may occur during the formation of a vein.

4. The duration of vein formation may be such that changes occur in the physical or chemical conditions of vein-forming fluids. Secondary inclusions also show wide variations in filling temperatures within a vein (see table 5-1). This suggests numerous periods of fracturing and the presence of numerous inclusion-forming fluids which vary widely in either temperature, pressure or salinity conditions.

Present in veins, containing primary inclusions with filling temperatures in the range 258° - 316°C, are secondary inclusions of similar filling temperatures to primary inclusions from other veins (see Table 5-1). This relationship suggests that veins with filling temperatures in the range 258 - 316°C occurred before veins with primary inclusion temperatures in the range of 202 - 240°C. The relationships between primary and secondary inclusion filling temperatures, discussed above,
may be interpreted in two possible ways; 1. That veins formed during a single waning phase of hydrothermal activity. The uniform mineralogy of quartz veins in the Golden Blocks area may support this interpretation. 2. Two major episodes of vein formation occurred. This interpretation is supported by structural data presented in Chapter IV section 10, in which quartz veins were found to be associated with Deformation Phases Four and Five; correlated with the Tuhua and Rangitata Orogenies respectively. The latter interpretation discussed above is favoured by the author.
VEIN STRUCTURES AND FORMATION PROCESSES

Two processes, fissure-infilling and replacement, are considered responsible for the formation of low temperature hydrothermal quartz veins (Bateman (1951), Chase (1949), McKinstry et al. (1949), Park and MacDiamid (1970), Stanton (1972)). The above authors also suggest that structures and features of the vein may be used to establish the process of vein formation. The reliability of these deductions and the process and mechanism of vein formation in the Golden Blocks area, is examined.

I  FISSURE-INFILLING VEIN FORMATIONAL PROCESSES

In this thesis, fissure-infilling is defined as a process by which quartz and other minerals are crystallized, or deposited from aqueous solutions in a pre-existing or contemporaneously opening rock fracture, fissure, joint or other tensional deformation structure. In the Golden Blocks area the following structures are a consequence of fissure-infilling vein formational processes;

1. Offset planar structures
2. Vug and comb structures
3. Crustification
4. Host-rock inclusions.
Plate 6-1  Vug and comb structures within a vein (U.C. 8000) as outlined by variations in fluid inclusion densities. These structures are associated with a second generation of vein quartz. Plane-polarised light.
(1) **Offset Planar Structures**

Planar structures (e.g. bedding, joints, veinlets) existing before cavity opening and vein formation, are disrupted, and in most cases, offset as a consequence of the opening of the vein cavity. For the offset of a planar structure to be apparent, this structure should intersect the fissure at an angle not more than fifty degrees, unless more than one such feature is present. In the Golden Blocks area, most vein occurrences are associated with thick to very thick sandstones, thus the use of bedding surfaces as a suitable planar structure is strictly limited. Joints and veinlets are the most commonly used planar structures. No evidence of replacement occurring along small fractures or shears along which planar structures are offset was observed in the Golden Blocks area. Offset planar structures are considered to be a reliable recognition criterion of vein formation by fissure-infilling.

(2) **Vugs and Comb Structures**

Vug cavities are common in veins cutting all lithologies. Comb structures were particularly common in thin veins present in thick to very thick sandstone lithologies. In Plate 6-1 the outlines of vug cavities and euhedral crystal shapes are revealed by variations in fluid inclusion densities.

McKinstry *et al.* (1949) suggest that vug cavities may result from an imbalance of dissolution and deposition existing during replacement. No record was given of

Plate 6-3. The intricate match of vein walls in this photograph indicates that the vein formed by fissure infilling. (U.C. 8003).
such occurrences, and in the Golden Blocks area vugs were not observed in veins thought to have formed solely by replacement. Most authors (Chase (1949), Stanton (1972), Bateman (1951)) consider that these structures are excellent evidence of fissure-infilling.

(3) **Crustification**

Examples of crustification were rarely observed. Shown in plate 6-2 is a quartz vein with an initial crustiform lining of mica. Such a feature is considered a reliable criterion of vein formation by fissure-infilling.

(4) **Host-Rock Inclusions**

In the Golden Blocks area veins known to have formed by fissure-infilling processes often contain host-rock inclusions. However, as similar host-rock inclusions are observed in replacement-type veins (Section 2-2), this structure cannot be used as a reliable criterion for suggesting the process of vein formation. This conclusion is contrary to the observations of Bateman (1951) and Rayboalt (1975). The intricate match of vein walls is observed in some veins in the Golden Blocks area, see Plate 6-3. However, the presence of host-rock inclusions in veins of this area which are known to have formed by replacement processes suggests that vein-wall match is not a reliable criterion of vein formation by this process.
Plate 6-4  This photograph shows a quartz cemented breccia. (U.C. 8008)
Although host-rock inclusions are not a reliable recognition criterion, the shape and distribution of host-rock inclusions in combination with other features of the vein, can be used to determine the mode of inclusion formation and the timing of fissure development in relation to vein formation. The following features of the vein shown in Plate 6-4 and its field occurrence suggest this vein represents fissure-infilling of a pre-existing breccia zone: 1. The angularity and close contact of host-rock inclusions.
2. The presence of vug cavities in the vein quartz.
3. In the field this vein contains some large host-rock inclusions which are as wide as the vein (250 mm). The close contact of host-rock inclusions within a vein, such as described above, is rare in the Golden Blocks area.

Host-rock inclusions are particularly common in linked veins present in thick to very thick sandstones. Inclusions in this type of vein, unlike the previous example, are generally completely surrounded by vein quartz. Fissure-infilling of numerous pre-existing linking fractures is considered the best explanation of this occurrence. Thus the host-rock inclusions represent portions of rock between adjacent or linked fractures.
Plate 6-5. This photomicrograph is completely composed of quartz except for three host rock inclusions. The thin sections, from which the photomicrograph was taken, came from the vein shown in Plates 6-7(a) and (b) and 6-8. Differences in fluid inclusion densities indicate that the vein is a composite of three generations of quartz. This is a consequence of repeated fracturing and vein formation. Note the vug and comb structures in the third generation of quartz. Plane-polarised light.
Observations concerning the development of host-rock inclusions in many veins in the Golden Blocks area indicate that fissure opening and vein formation is synchronous or contemporaneous. The vein shown in Plate 6-5 is a composite of three generations of quartz. Differences in fluid inclusion densities are used to discriminate between the various generations of quartz. The nature of this vein, which is composed of numerous individual veinlets, suggests that cavity formation occurs as a series of fissure openings. Plate 6-6, a photomicrograph of the same quartz vein shown in Plate 6-5, shows a thin elongate host-rock inclusion present at the contact between two phases of quartz. The contact between the vein and its host-rock is a plane of weakness, along which fracturing and vein formation can occur. The thinning of vein A in Plate 6-6 and the occurrence of the elongate host-rock inclusion at the contact between vein A and vein B, suggests that the inclusion represents the remains of the original vein-wall to vein A. The host-rock inclusion was attached to, and subsequently included, in the quartz vein (veinlets A and B) during the formation of veinlet B in a fracture or cavity at the contact between host-rock and vein A. By this mechanism sub-parallel, elongate host-rock inclusions may be formed within a vein formed by fissure-infilling (see Plate 6-7). Fissure-infilling veins which contain this type of host-rock inclusion and which are composed of numerous veinlets are considered the
Plate 6-6  This photomicrograph is taken from the same thin section as Plate 6-5. Shown in the photomicrograph is the contact between a quartz vein and its wall rock. Differences in the densities of fluid inclusions within vein quartz suggests three generations of quartz within this photograph. The timing of vein A to the left suggests it predates vein B. An elongate host-rock inclusion occurs at the contact between Vein A and Vein B. This suggests that the host-rock inclusion represents a remnant of the vein wall rock to vein A. Plane-polarised light (U.C. 8010).
Plate 6-7  This photomicrograph shows large elongate parallel host-rock inclusions within a vein (U.C. 8010) which are semi-parallel to the walls of the vein. The darker areas of quartz in the vein represent drusy quartz.

Plate 6-8  Vug and comb structures indicate that this vein, which cuts a sandstone was formed by fissure infilling processes. The large host-rock inclusion (Fred) cannot be fitted back into the walls of the vein, whereas other large inclusions can. This suggests movement or rotation of this inclusion within the vein cavity (U.C. 8010).
result of repeated fracturing accompanied by, or synchronous with, vein formation.

The movement of host-rock inclusions within the vein cavity can be demonstrated in some fissure-infilling type veins. The large inclusion within Plate 6-8 cannot be matched with the vein wall, suggesting movement or rotation of this inclusion within the vein. The movement of the inclusion in vein A, Plate 6-9, prior to quartz crystallization, is suggested by its position between the vein walls containing the offset halves of vein B. The slight offset of vein B and the presence of vug cavities, indicates that vein A formed by fissure-infilling processes. Phillips (1972) formulated a mechanism termed hydraulic fracturing to explain mineralized fault zones in which the quartz lodes contained numerous angular country rock fragments. This mechanism involves the build up of high pore water pressures along pre-existing fault planes, which reduces the stresses required for fracturing. Once these stresses are exceeded, hydraulic fracturing occurs. The resulting low pressure envelope about a fracture, causes rapid migration of pore fluids towards the fracture, and brecciation of the surrounding rock results. From studies of veins in the Golden Blocks area, it is not possible to infer that high pore water pressures were responsible for fracture and fault initiation; tectonic events alone could adequately explain the development of these structures. However, the rapid migration of fluid into and along fracture cavities may explain the formation, displacement
Plate 6-9 The slight offset of vein B across vein A indicates vein A formed by fissure infilling. Vein A contains a host rock inclusion. The movement of this inclusion within the cavity of vein A prior to quartz crystallization is suggested by the position of this inclusion between the portion of vein walls containing the offset halves of vein B. (U.C. 8009)
and rotation of some host-rock inclusions. Other mechanisms may also explain the movement of host-rock inclusions within vein cavities: 1. the differential growth of quartz 2. shearing movements prior to quartz crystallization.

A study of host-rock inclusions in the Golden Blocks area indicates these structures may form in a number of different ways, and that fissure opening is often accompanied by vein formation.

II REPLACEMENT VEIN FORMATION PROCESSES

For the purpose of this thesis replacement is defined as a process

"of practically simultaneous capillary solution and deposition by which a new mineral of partly or wholly differing chemical composition may grow in the body of an old mineral or mineral aggregate".

Dictionary of Geological Terms, Pg 420.

The following features were observed in veins formed by replacement in the Golden Blocks area:

1. Non-offset planar structures
2. Relic sediment structures
3. Unreplaced residuals of host-rock
4. Concentrations of micas and chlorites.
Plate 6-10 (a) This photomicrograph shows two generations of quartz veins cutting a mudstone. The two veinlets clearly post-date the larger vein. The lack of offset along the veinlets indicates that the larger vein which contains host-rock inclusions was formed by replacement processes. Cross-polarised light (U.C. 8004).

Plate 6-10 (b) A photomicrography of the same vein showing the presence of numerous flakes of chlorite and sericite within the vein formed by replacement. This feature is a characteristic of veins formed by replacement. Plane-polarised light.
(1) **Non-offset Planar Structures**

Vein formation by replacement does not involve the opening of a vein cavity, thus the alignment of planar structures present before vein formation is not disrupted or offset. Shown in Plates 6-10 (a) and (b) is an example from the Golden Blocks area of the non-offset of a vein formed by replacement. The lack of suitable planar structures in the Golden Blocks area restricts the use of this feature as a vein recognition criterion.

(2) **Relic Sediment Textures**

Textural features of vein host-rocks may be preserved during vein formation by replacement. Two types of carbonaceous material, types A and B, are recognised in Plates 6-11 (a) and (b). Type B carbonaceous material is considered to be the result of pressure solution processes which occurred after vein formation. Type A carbonaceous material which is associated with "dusty" vein quartz is parallel to similar accumulations in irregular-shaped host-rock inclusions. This relationship suggests that the vein quartz was formed by replacement. The carbonaceous material enclosed in this quartz is considered to represent relic host-rock textures, possibly stylolitic structures developed prior to vein formation. Relic sediment textures are rarely observed in the Golden Blocks area and require careful and detailed study to establish the nature of these features. Therefore,
Plate 6-11 (a) The parallel alignment of type A accumulations in irregular host rock inclusions suggests that the vein quartz was formed by replacement processes. The 'dusty' appearance of vein quartz, due to numerous flakes of sericite and chlorite, is characteristic of quartz formed by replacement processes. Plane-polarised light.

Plate 6-11 (b) Similar accumulations of carbonaceous material associated with irregular host-rock inclusion. Plane-Polarised light. Note the development of stylolites in both plates at oblique angles to structures described above.
the value of these structures in determining the process of vein formation is strictly limited.

(3) Unreplaced Residuals of Host-Rock

A vein, which formed by replacement processes, as indicated by the offset of two veinlets, is shown in Plates 6-10 (a) and (b). The host-rock inclusion within this replacement type vein represents an unreplaced residual of host-rock. The presence of host-rock inclusions within a vein is not considered a reliable indicator as to the process of vein formation, because similar features also occur within fissure-infilling type veins.

(4) Mica and Chlorite Concentrations

Quartz veins present in mudstone sediments, which are known to be formed by replacement processes, often have a dusty appearance due to the presence of numerous, randomly distributed flakes of mica and chlorite (see plates 6-10 and 11). The mica and chlorite flakes probably result from the replacement of clay and micaceous constituents of vein host-rocks. Fissure infilling veins in comparison, contain virtually no randomly distributed mica or chlorite flakes. If mica or chlorite is present within a fissure-infilling type vein it is generally present as crustiform linings.

The practical value of this feature as a vein process recognition criterion is limited because the
Plate 6-12 (a) This photomicrograph shows a quartz vein (U.C. 8007) containing a stylolite and several host-rock inclusions. The stylolite is developed perpendicular to the stress orientation indicated by a pyrite strain shadow (Plate 12(b)). Note the fracture pattern visible within the quartz grains. Plane-polarised light.

Plate 6-12 (b) This photomicrograph is a magnified portion of a host-rock inclusion present in Plate 6-12(a). Shown in the photomicrograph is a strain shadow about surrounding a pyrite in the host-rock inclusion. Stylolites at the margin of the host-rock inclusion are perpendicular to the stress orientation shown by the pyrite strain shadow. Note the presence of discontinuous deformation lamellae within vein quartz grains. Plane-polarised light.
vein host-rock must be of suitable composition to form mica and chlorite and thin-section studies are required to identify the texture and composition of these minerals.

III NON-VEIN FORMATIONAL STRUCTURES

Studies of veins in the Golden Blocks area indicate that many veins contain structures or features which are the result of processes other than vein formational processes. These non-vein formational processes have been neglected by previous workers, such as McKinstry et.al. (1949) and Chase (1949), when explaining the development of some vein structures, in particular, those involving carbonaceous material.

(1) Stylolites
Stylolite-like accumulations of carbonaceous matter are commonly observed in veins of the Golden Blocks area. Stylolites, which are formed by pressure solution processes, are commonly observed in sediments. Meta-sediments of the Golden Blocks area frequently contain these structures (Chapter III section 2-1(b)). Stress orientation indicators in sediments show that stylolites develop perpendicular to the maximum compressive stress (Dunington (1954), Mead (1955), Trurnit (1968), Ritenhouse (1971)). The accumulations of carbonaceous and micaceous material shown in Plates 6-12 (a) and (b), which occur within vein quartz, are the result of pressure
Figure 6-1 Illustrated in this diagram are the angular relationships between stylolites, a pyrite strain shadow, discontinuous deformation lamellae and micro fractures (included in this category are continuous deformation lamellae) within the vein shown in Plates 6-12 (a) and (b). The angular relationships indicate that the stress causing the formation of stylolites was also responsible for the formation of micro fractures and possibly discontinuous deformation lamellae within this vein.

![Graph showing the angular relationships between different structures.](chart.png)

**Structure**
- **Stylolites**
- **Microfractures**
- **Deformation Lamellae**
- **Pyrite Strain Shadow**

**KEY**

![Key for the diagram.](key.png)
solution processes because they develop perpendicular to the maximum compressive stress direction as indicated by the pyrite strain shadow. The relationships shown in Figure 6-1 suggest that the compressive stress causing the formation of the stylolitic structures also may have been responsible for the formation of microfractures and discontinuous deformation lamellae in quartz grains of this vein. Examples, such as the one above, in which the vein contained suitable stress orientation indicators, are rare and generally other features of the vein must be used to indicate the role of pressure solution processes in the formation of stylolitic structures.

Plates 6-13 (a) and (b) show a vein containing a prominent accumulation of carbonaceous material, above which the vein quartz is composed of large, optically uniform quartz crystals which are free of inclusions of carbonaceous matter. Below this structure the vein quartz is micro-crystalline and contains numerous scattered inclusions of carbonaceous material. The occurrence and morphology of this accumulation of carbonaceous material is best explained by the pressure solution of quartz and the accumulation of carbonaceous matter on the bottom surface of this structure and by the deposition of quartz at the upper surface. The occurrence of this stylolitic-like structure and similar features in other veins is considered consistent with their formation by pressure solution processes. Downward migration of the
Plate 6-13 (a) shows a prominent stylolite within the vein quartz (U.C. 8004). The lack of carbonaceous matter in the quartz above the stylolite suggests that pressure solution occurred at the lower surface. Plane-polarised light.

Plate 6-13 (b) This is the same section as Plate 6-13(a), under crossed polarised light showing the presence of large quartz grains above the stylolite. This suggests that crystal growth occurred at the upper surface of the stylolite which resulted in a downward migration of the stylolite surface.
Plate 6-14 (a) This photomicrograph is of a host-rock inclusion present within the vein shown in Plate 6-11(a), (U.C. 8004). The nature of vein offsets clearly indicates pressure solution effects at a surface marked by an accumulation of carbonaceous material. Stylolite formation clearly post-dates vein formation in this photomicrograph. Plane-polarised light.

Plate 6-14 (b) This photomicrograph is a larger view of the host-rock inclusion shown in Plate 6-14(a). Veinlet A crosscuts a stylolite surface indicating vein formation also occurred after stylolite formation. The thick accumulation of carbonaceous material shown (see arrows) suggests that pressure solution effects may be an important source of vein formation solutions. Plane-polarised light.
stylolite illustrated in Plates 6-13 (a) and (b) would be expected as a result of crystal growth at the stylolite's upper surface and pressure solution at its lower surface. Euhedral pyrite and marcasite are associated with carbonaceous material of the stylolite. This association, which is observed in numerous other slides, suggests that pressure solution processes may be important in the localised, post-vein formation remobilization or redistribution of sulphide and gold within the vein. Extensive development of stylolites within a vein could obliterate original vein formation textures and thus make determination of the mode of vein formation impossible.

Unlike the example discussed above where pressure solution pressure processes are considered responsible for a re-organization of vein constituents structures associated with other stylolites in veins indicate that stylolite formation may be an important source of vein or pore fluids. Vein offsets, shown in Plates 6-14 (a) and (b) indicate that approximately 0.2mm of rock was removed by pressure solution effects. The thick accumulations of carbonaceous material shown in Plate 6-14 (b) suggest that this process may be responsible for the removal of large quantities of host-rock and for the generation of significant volumes of pore or vein fluids.
Stylolites in host-rock inclusions and vein wall-rocks, indicate that stylolite formation may occur prior to or post-date vein formation as shown in Plate 6-14(b). Also, several orientations of stylolitic structures may be recognised within a single vein. However, stylolites, when observed in association with fissure-infilling veins, often have attitudes which are parallel or semi-parallel to the margins of the vein. These relationships may imply that tensional features (fissure opening) are followed by compressional structures (i.e. pressure solution effects) with the same stress orientation. The development of secondary inclusion trails (recrystalized fracture zones) at right angles to the vein walls may support this observation.

Previous workers such as McKinstry et al. (1949) appear to have neglected the possible effect of pressure solution processes on the development and distribution of carbonaceous material within veins. The importance of this stress-induced process in the formation of features within veins of the Golden Blocks area emphasises the effect of continued deformation after vein formation.

(2) Fractured, Slickensided and Brecciated Quartz

Veins in the Golden Blocks area are often fractured, slickensided and brecciated by deformation events occurring subsequent to vein formation. For example, reactivation of N-S and E-W fault planes at the Aorangi
Plate 6-15 (a) Illustrated is a hand specimen of a quartz vein clearly showing several fracture sets within the vein. One fracture set is filled with dark-coloured material.

Plate 6-15 (b) is a photomicrograph of a thin section (U.C. 8005) made from the vein shown in Plate 6-15 (a). This shows part of a fracture, surrounded by quartz containing deformation bands, which is filled with detrital quartz grains and carbonaceous material. Sedimentary material in the left hand fracture is cut by a veinlet of quartz. The right hand fracture shows evidence of en-echelon shearing. Plane-polarised light.
Mine (628,556) has resulted in the fracturing, shearing and slickensiding of quartz veins within the fault plane.

Plate 6-15(a) shows a vein which contains several fracture sets; one of which is filled by detrital quartz grains and carbonaceous matter (Plate 15(b)). A mechanism which is analogous to that proposed for brecciation of host-rocks about a fracture cavity (section 1-4), may best explain this occurrence. A fracture cavity at the time of formation represents a zone of low pressure compared with the surrounding rocks and the movement of pore solutions into this cavity along the resulting pressure gradient is expected to occur. This movement of solutions could transport detrital material. In the vein shown in Plate 6-15(a)(b) detrital material is confined to certain fracture sets which suggests particular conditions are required for the formation of this feature. These are:

1. high pressure gradients; these would increase with increasing depth of fracture formation.
2. The presence of pore fluids in the rocks surrounding the fracture. The occurrence of carbonaceous matter described above represents another example of the formation of this material within a vein, by processes which are not a consequence of vein formational processes.

The heating and recrystallization of fractures within some veins may result in the formation of phantom veinlets, so named because they are composed of water-clear quartz;
a result of low fluid inclusion densities.

The presence of fractured, brecciated and slickensided quartz indicates that deformation events continued after episodes of vein formation.

IV VEIN FORMATIONAL PROCESSES IN THE GOLDEN BLOCKS AREA; AN ASSESSMENT OF RELATIVE IMPORTANCE

When attempting to establish the relative importance of various vein formational processes within an area, it is essential to find a comparable feature or structure which results from either replacement or fissure-infilling vein formational processes. Comparisons of features or structures which are a result of the vein formation process, such as vugs, crustification and relic host-rock structures, are not possible because the number of such features depends on the conditions prevailing during vein formation. The offset or continuity of planar structures provides a reliable and comparable indicator as to the process of vein formation because 1. these structures are not a result of processes acting within the vein and 2. a finite number of such structures are present before vein formation; thus these structures should have an equal probability of affecting veins formed by fissure-infilling or by replacement. It is also necessary to define on which scale comparisons are made. For example, relic host rock structures require careful study in thin-section before it is possible to positively
identify these structures.

In an attempt to determine the dominant vein formational process in the Golden Blocks area, forty-eight hand specimens containing veins were studied. Although these samples contain approximately two hundred and fifty individual veinlets, only sixteen planar features which intersected veins were observed. The results of this study (see Table 6-1), although based on limited data, indicate that fissure-infilling is the dominant process of vein formation in the Golden Blocks area.

Table 6-1 Mode of Vein Formation

<table>
<thead>
<tr>
<th>Process:</th>
<th>Fissure infilling</th>
<th>Replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure:</td>
<td>Offset Planar</td>
<td>Continuous</td>
</tr>
<tr>
<td></td>
<td>Structures</td>
<td>Planar Structures</td>
</tr>
<tr>
<td>Numbers:</td>
<td>13</td>
<td>3</td>
</tr>
</tbody>
</table>

Field observation and thin section studies of veins in the Golden Blocks area also provides data, which although it is not comparable, suggests that fissure-infilling is the dominant vein formational process. Vug and drusy cavities are particularly common in veins present in sandstones. The predominance of fissure-infilling processes in sandstones is possibly a reflection of the
brittle response of this lithology to stress which creates numerous sites for the formation of veins. Thin-section studies of mudstones indicate that veins in this lithotype often form a mesh of veinlets, some of which result from replacement processes. Many of the replacement-type veins in mudstones are cut by fissure-infilling-type veins suggesting that many of the replacement-type veins may be associated with an earlier and different episode of vein formation.

The mode of vein formation appears to have no affect on sulphide deposition within the vein or surrounding host rock. For example, arsenopyrite was observed in a vein clearly formed by fissure-infilling. Yet this sulphide clearly replaces constituents of the vein host rock. No observations were made concerning the mode of formation of veins containing gold. As demonstrated previously (see section 3-7) the nature of the vein host rock and its effect on vein solutions is possibly more important in determining mineral deposition than is the mode of vein formation.
<table>
<thead>
<tr>
<th>Mine</th>
<th>Altitude ft. A.S.L.</th>
<th>Evidence of Weathering or Supergene Enrichment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aorangi</td>
<td>1200</td>
<td>Richest portions of lodes occur between outcrop and No. 1 level (Bell et al. 1907). Leaching occurs to greater depths along permeable zones, e.g. fault intersections. However, satisfactory primary gold values occur below creek level.</td>
</tr>
<tr>
<td>Anthill</td>
<td>1000</td>
<td>The Anthill fault plane and the contact between Members AM1 and AM2 are extensively weathered. Gold values decreased in unweathered argillites. (Bell et al. (1907).)</td>
</tr>
<tr>
<td>Fault Adits</td>
<td>1000</td>
<td>Mudstones in mine are leached. Basal Cretaceous - Tertiary sediments occur within 10 metres of the mine.</td>
</tr>
<tr>
<td>Golden Ridge</td>
<td>1000</td>
<td>Mudstones in the mineralized zone are extensively leached.</td>
</tr>
<tr>
<td>New Find</td>
<td>850</td>
<td>Mudstones in stope areas are extensively weathered. Basal Cretaceous - Tertiary sediments overlie mine workings.</td>
</tr>
<tr>
<td>(Old Golden Ridge)</td>
<td>650</td>
<td>Outcrops of Member AM1 are extensively weathered. Cretaceous - Tertiary coal measures outcrop immediately above the mine.</td>
</tr>
<tr>
<td>Morning Star</td>
<td>550</td>
<td>Sediments within the mine appear unweathered.</td>
</tr>
<tr>
<td>Friday Creek</td>
<td>600</td>
<td>Paleozoic sediments are extensively weathered. Cretaceous - Tertiary sediments outcrop 300 metres to the north.</td>
</tr>
</tbody>
</table>
CHAPTER VII

SUPERGENE WEATHERING AND ENRICHMENT

I INTRODUCTION

As summarised in Table 7-1 Paleozoic sediments associated with mineralized zones at most mine localities in the Golden Blocks area are generally extensively leached and weathered. See Chapter IV sections 1-8 for detailed descriptions. Bell et.al. (1907) reported that the richest gold values at the Aorangi and Anthill Mines occurred near the surface, and that gold values decreased rapidly below the zone of weathering. These authors considered that the association of the rich pay shoots and economic quartz lodes with weathered and leached lode host-rocks indicated the supergene enrichment of gold by weathering solutions. This interpretation is supported by the author. Gold values quoted as "satisfactory" are reported from the fourth level at the Aorangi Mine (Papers and Reports Relating to Minerals and Mining (1912)) however, the numerical value of the ore was not recorded. It is very probable that the lode and lode host-rocks at the fourth level are below the possible zone of supergene enrichment because this level is approximately fifteen metres below the creek bed of Little Slaty Creek. Therefore the satisfactory values quoted for lodes at this level, if present, probably represent primary gold values which are of economic grade.
Figure 7-1 The relationship of gold mines in the Golden Blocks area to the distribution of Pakawau Group sediments.
Metasediments in mine tailings from the bottom two levels of the Morning Star Mine appear unweathered. This suggests that much of the ore mined from these levels may have been obtained from primary ore lodes of economic grade.

Paleozoic sediments at the Old Golden Ridge, New Find, Fault Adits and Friday Creek Mines are unconformably overlain by Upper Cretaceous to Tertiary coal measures, mudstones and conglomerates of the Pakawau Group (see Table 7-1). To the north of these mine localities thicker sequences of Pakawau Group sediments occur (see figure 7-1). Basal sediments of this group are associated with a poorly developed but areally extensive weathering surface which is tilted slightly to the north. Remnant outliers of Cretaceous-Tertiary sediments which are associated with hollows in this weathering surface unconformably overlie paleozoic sediments in the central portions of the Golden Blocks area as shown in figure 7-1. Figure 7-1 also shows the close association of productive mineralized zones in the Golden Blocks area with the outcrop of the weathering surface. This surface, unlike the Upper Cretaceous Peneplain which is preserved over much of north-west Nelson, is poorly developed and has a considerable relief of up to 100 metres (see Plate 7-1). Extensive deep weathering of the Paleozoic sediments only occurs to depth of 30 metres along deformation zones because of the poor development of this weathering surface. The association of this Cretaceous-Tertiary weathering
Plate 7-1   View of Lt. Baldy and Big Slaty Creek Gorge from the vicinity of the Golden Ridge Mine. Remnant outliers of Cretaceous-Tertiary sediments mantle the slopes of Lt. Baldy (see arrows). Up to 100 metres relief on the exhumed surface is clearly indicated.
surface with weathered metasediments at mine localities (Table 7-1 and figure 7-1) suggests that this surface was the source of solutions responsible for supergene enrichment of mineralized lodes in the Golden Blocks area. The present drainage system dissecting Paleozoic sediments in this area is considered largely a result of the antecedent drainage system developed on the Cretaceous-Tertiary weathering surface; erosion being the major feature of the present weathering cycle (see Plate 7-1).

(1) Supergene Weathering Processes; The Possible Role of Sedimentary Pyrite

Limonitic boxworks, gossans and secondary minerals are features generally associated with classic examples of supergene enrichment (Bateman (1951)). These features are absent at mine localities in the Golden Blocks area. A study of the Calhoun Mine by Lesure (1971) and Kinkel et al. (1968) showed that small quantities of pyrite (0.5 - 1%) in vein host-rock and veins was sufficient to cause supergene enrichment of gold. Although no gossans or secondary minerals occur at this locality, gold values were enhanced five times. In the Golden Blocks area, quartz lodes contain only small quantities of pyrite (usually less than 0.5%) and only trace amounts of copper, zinc and lead sulphides. However, lode host-rocks contain significant quantities of pyrite (up to 5%). As lode host-rocks are often extensively leached and weathered, especially near the
surface, weathering of sedimentary pyrite in these rocks may have been the source of acid solutions responsible for the supergene enrichment of gold at mine localities in this area. The relatively small amount of pyrite present in Paleozoic meta-sediments and in the quartz lodes, and the presence of only trace quantities of copper, zinc and lead sulphides, may explain the lack of gossans, boxworks and secondary minerals in the lodes of the Golden Blocks area.
Two dominant stages of development are recognised in the formation of gold and sparse sulphide mineralization in the Golden Blocks area. These are as follows:

1. Initial mineralization associated with hydrothermal quartz veins; primary mineralization.
2. Remobilization and redistribution of primary mineralization by supergene processes; secondary mineralization.

I THE NATURE OF THE HYDROTHERMAL SYSTEM AND THE SOURCE OF HYDROTHERMAL PHASES

Primary gold and basemetal mineralization in the Golden Blocks area is associated with hydrothermal quartz veins, the character and distribution of which, reflect the nature of the hydrothermal system. The hydrothermal system may represent a mineral transport mechanism as gold can be readily transported as complexes in hydrothermal phases (Henley (1975), Rytuda and Dickson (1974)).

Primary mineralization and the dominant episodes of vein formation are associated with Deformation Phases Four and Five which are late stage tectonic events and
FIGURE 8-1

FEATURES CONTROLLING THE DISTRIBUTION OF VEINS IN MUDSTONE AND SANDSTONE LITHOLOGIES.
the importance of tectonism in relation to the nature of the hydrothermal system is further emphasized by predominance of fissure-infilling-type veins in the Golden Blocks area (see Chapter VI). The further importance of tectonic features is indicated by figure 8-1 which shows that deformation zones (i.e. faults, shear zones, joints and fractures) are the major features controlling the distribution of veins in sandstone and mudstone lithologies in the vicinity of the Aorangi Mine. Many of the veins which are developed parallel to bedding in mudstones are associated with bedding plane shears. As shown in figure 8-2, sandstone units in the Golden Blocks area contain more quartz veins than do mudstones. This variation in vein densities is primarily considered a result of different responses of these lithologies to deformation. Sandstones react competently to stress which results in numerous fractures and joints which represent favourable sites for vein formation and permeable zones for the movement of ore fluids. In contrast, mudstones appear to respond incompetently to stress and thus few potential sites for vein formation are produced.

Members AM₁ and AM₄ which are predominantly composed of sandstones contain higher densities of veins than do the Webb and Sandhills Creek Formations, which are of similar composition (see figure 8-2). The higher densities of veins in these units which are in contact
Figure 8-2 The variation in densities of quartz veins in relation to bedding type and lithology.
with mudstones of Members AM$_2$ and AM$_3$, may reflect the inhomogeneous stress suffered by these sandstones due to the different response to deformation of sandstones and mudstones; lithologies of differing competencies. This style of deformation may have been responsible for the development of N-S striking faults which are particularly common near lithologic contacts (see Chapter III).

In the Golden Blocks area sandstones and, in particular, deformation zones in this lithotype are considered to have acted as conduits for the movement of hydrothermal phases (see figures 8-1 and 8-2). Structures correlated with Deformation Phases Four and Five, which are associated with the two major episodes of quartz vein formation, are considered to be initiated by orogenic tectonic movements (see Chapters III and IV). High pore water pressures do not appear responsible for the initiation of faults and fractures (hydraulic fracturing; Phillips (1973)) however, high pore water pressures may have aided fault movement and promoted fracture development.

Without definitive evidence any suggestion as to the source of hydrothermal phases are speculative. However, some observations on the nature and relationships of vein system are considered to place limits on the source of vein fluids. No evidence of metamorphic events or their
relationships to tectonic events can be observed in the Paleozoic sediments of the Golden Blocks area. However, granite intrusion and thermal metamorphic events are part of the orogenic events with which major episodes of vein formation are correlated (See Chapters III and IV). Thus such events affecting rocks at deeper levels in the crust than the Paleozoic rocks presently exposed in the Golden Blocks area may have been responsible for the generation of hydrothermal phases.

The envisaged mechanism of vein formation suggests that fluid movement within the vein system was in response to pressure rather than temperature gradients. Thus meteoric waters which generally circulate in response to temperature gradients are thus considered an unlikely source of hydrothermal fluids.

In the Golden Blocks area the hydrothermal systems responsible for the formation of both major episodes of vein formation, are envisaged as hydrothermal phases of metamorphic, connate, or magmatic derivation which move mainly in response to pressure gradients through deformation zones in sandstones, and less frequently through mudstone lithotypes.
II POSSIBLE SOURCES OF GOLD: A DISCUSSION

Mineralized occurrences in mudstone units in the Sandhills Creek Formation (Friday Creek Mine and Tinnes Creek Lodes) are associated with volcanogenic sandstones (Chapter IV section 9). The Mine Bed, the highest gold producing horizon in the Golden Blocks area, occurs twenty to fifty metres stratigraphically above a twenty metre thick volcanogenic sandstone unit near the top of Member AM1. The mineralized zone of a minor auriferous occurrence, the Fault Adits Mine, is confined to a mudstone associated with this volcanogenic sandstone. Henley et al. (1976) considered the Central Otago metavolcanic belt to be a likely source of gold mineralization associated with quartz lodes of this area. Grindley et al. (1960) believed that the Haupiri Schists, which are composed of volcanogenic sediments, constituted a possible source of gold-silver and base-metal mineralization in the Aorere Valley, because of a relatively high percentage of ore minerals in these schists. In the Golden Blocks area the association of weak gold mineralization with volcanogenic sediments and the close stratigraphic relationship of these sediments to the most favourable ore horizon, the Mine Bed, suggest that volcanogenic sediments are a likely source of leachable gold and sulphides for the formation of ore deposits in this area. However, other sources of gold can not be excluded and must also be considered.
The presence of clasts of Mine Bed mudstones in overlying sandstones and the considerable variation in the thickness of the Mine Bed indicates erosion of the upper surface of this unit (see Chapter II). Erosional processes could result in placer concentrations of gold at the eroded surface. However, because of the lack of data concerning the depositional environment of Paleozoic sediments in the Golden Blocks and surrounding areas, this hypothesis must be regarded as speculative. The lack of mudstone clasts and volcanogenic sediments in Member AM$_4$ indicates that alternative sources of gold other than those proposed above, must be responsible for the formation of mineralized zones in Member AM$_3$ (Old Golden Ridge and Morning Stars Mines) near its contact with Member AM$_4$.

It has been well documented that mudstones, especially black shales, contain anomalous quantities of heavy metals compared with other sediments (Krauskopf (1955), Radar (1961), Rösl er et al. (1972), Turekian et al. (1961)). Although carbonaceous mudstones in the Golden Blocks area are intimately associated with hydrothermal quartz lodes, these sediments are not considered the immediate source of the gold because fluids causing vein formation in this lithology are derived via adjacent sandstone units (see Section 3). However, pore fluid movement during sediment compaction or diagenesis may have transported and concentrated gold and sulphides into adjacent porous sandstone units. Microveinlets
composed of carbonaceous material, sulphides and quartz in sandstones and mudstones (u.c.) may support this otherwise rather speculative hypothesis.

Tilling et al. (1973) found that both sediments and igneous rocks contain only minute quantities of gold (i.e. the average gold content of mudstones is less than 30 ppb; of igneous rocks less than 5 ppb). These authors considered that it is unlikely that any particular rock type can represent a more favourable source of gold because a concentration factor of 1000 times is required to produce a gold ore. Thus the availability of gold and the permeability of the rock type to hydrothermal phases rather than the "anomalous" gold content of a particular rock type, are possibly the most important factors to be considered when evaluating potential sources of trace metals. The intergranular movement of connate fluids into a fissure cavity subsequent to fissure opening could be responsible for the leaching and transport of the trace amounts of gold associated with sandstones.

Ascending hydrothermal fluids of metamorphic, connate or magmatic derivation may leach gold and sulphides from permeable Paleozoic metasediments (i.e. sandstones) at levels deeper than that observed in the Golden Blocks area. Although a sedimentary source of the gold and basemetal mineralization present in the Golden Blocks area is favoured by the author, a magmatic source of the gold can not be disregarded.
III CONTROLS ON THE FORMATION OF PRIMARY MINERALIZATION

(a) Solution Wall-rock Interactions

Primary gold and basemetal mineralization in The Golden Blocks area is confined to specific Paleozoic mudstone lithologies (Chapter IV section 9). Ninety-seven percent of the gold production of the Golden Blocks area was won from mudstones which contain carbonaceous material with only three percent of the total gold yield obtained from non-carbonaceous mudstones. Eugster and Skippen (1967) suggest that carbonaceous matter affects the oxygen fugacities of ore fluids causing the deposition of ore minerals. Grindley et al. (1960) reported that gold-silver and basemetal mineralization in the Aorere Valley, north-west Nelson, is concentrated along a low angle thrust contact between the Aorere and Haupiri Groups. These authors considered that the carbonaceous content of the Aorere Schists was responsible for the deposition of ore minerals. Thus the association of mineralized zones in the Golden Blocks area with mudstones is considered to be the result of solution wall-rock interactions between hydrothermal phases and constituents of mudstone lithologies.

(b) The Mechanism of Lode Formation in Mudstones

Solution wall-rock interactions are considered responsible for the deposition of gold and sulphides in mudstones of the Golden Blocks area. However, auriferous occurrences in this area do not occur throughout mudstone
GEOLOGY OF AORANGI MINE AREA

FIGURE 8-3

DIAGRAMMATIC REPRESENTATION OF THE DISTRIBUTION OF VEINS IN DEFORMATION ZONES CUTTING DIFFERENT LITHOLOGIES AT THE AORANGI MINE.
sequences but are confined to particular mudstones which are associated with sandstone units (Chapter IV section 9). This control on the distribution of mineralized zones is considered a result of the mechanism of vein formation in mudstone. The low numbers of veins in mudstones, see figure 8-2, is considered the result of a plastic response of this lithology to deformation. This restricts the movement of hydrothermal fluids and inhibits the development of suitable sites for vein formation. As illustrated in figure 8-3, a geologic map of the Aorangi Mine, deformation zones within mudstone sequences do not contain quartz veins. Quartz vein occurrences in mudstones at the Aorangi Mine and at other auriferous occurrences in the Golden Blocks area are confined to those portions of deformation zones which occur close to or intersect sandstone units. This distribution of quartz veins suggests that veins in mudstones are formed from solutions derived via the adjacent sandstone units.

Because of the restricted movement of mineralizing hydrothermal phases in mudstones, various factors regarding the stratigraphic occurrence of mudstones, such as carbonaceous content (solution wall-rock interactions), bed thickness, lateral extent and relationship to sandstones will affect the favourability of a particular mudstone as a site of vein formation and mineralization. Mineralized zones at the Morning Star, Old Golden Ridge and Anthill Mines are confined to mudstones near or at the contacts
of Members AM₂ and AM₃, which are thick, widespread mudstone units, with sandstones of Members AM₁ and AM₄. The above mines, associated with this type of mudstone occurrence, produced twenty-three percent of the total gold yield of the Golden Blocks area. Seventy-five percent of gold production of this area came from the Mine Bed; a carbonaceous mudstone. This unit represents a favourable horizon for vein formation because this thin (less than 40 metres thick) mudstone unit is flanked by very thick sandstone beds and competency differences between these lithotypes causes the development of intense zones of deformation, many of which are permeable to the movement of hydrothermal phases. Mudstone units present in the Sandhills Creek Formation, although thin (10-30 metres thick) and flanked by sandstone beds, are not favourable units for mineralization because of the limited extent of these beds and the non-carbonaceous nature of the mudstones.

The extent of deformation zones is considered to be a major factor influencing the potential gold yield of individual mineralized zones. The extent of a deformation zone is determined to a large degree by its orientation with respect to the strike and dip of the mudstone unit. For example, most of the auriferous lodes at the Aorangi Mine are associated with the Aorangi Fault which has a similar strike to that of the Mine Bed. This results in a laterally extensive deformation zone. In comparison
the deformation zone of E-W striking faults which intersect the Mine Bed in this area are far less extensive (see figure 8-3).

IV FACTORS CONTROLLING SECONDARY MINERALIZATION PROCESSES

In the Golden Blocks area supergene solutions associated with the Upper Cretaceous weathering surface are responsible for the weathering of Paleozoic rocks and for the enhancement of the generally uneconomic tenor of the primary gold mineralization to payable grades (see Chapter VII). Probably, less than five percent of gold production in the Golden Blocks area was won from primary gold lodes. Thus supergene processes are considered the primary factor controlling the distribution of productive mines in this area. The distribution of enriched lodes is affected by the following: 1. The distribution of primary mineralization which has been discussed previously.

2. The development and topography of the Upper Cretaceous weathering surface.

3. The effect of recent weathering processes on the preservation of the Upper Cretaceous weathering surface.

The Upper Cretaceous weathering surface in the Golden Blocks area is poorly developed with a relief of two to three hundred metres (see Plate 7-1) and is unlike the well developed peneplain surface observed in other
parts of north-west Nelson (Grindley et al. (1960)). Weathering of Paleozoic sediments in the Golden Blocks area is usually confined to less than five metres except along deformation zones where lodes and lode host-rocks are often extensively weathered to depths of ten to twenty metres. Quartz lodes represent permeable zones which allow the downward movement of supergene solutions to depths of forty metres below the weathering surface (Chapter IV section 1). All of the productive mines in the Golden Blocks area except the Morning Star Mine, are located on the tops or flanks of ridges in the Upper Cretaceous weathering surface. As shown diagrammatically in figure 8-4, the topography of these ridges may have influenced the configuration of the water table in the vicinity of mines which promoted the deeper percolation of weathering solutions along deformation zones than might otherwise be expected. In the Golden Blocks area development of enriched zones of mineralization are restricted to those lodes permeable to supergene solution movement which occur close to or intersect the Upper Cretaceous weathering surface.

In the central portion of the Golden Blocks area the topography of the exhumed Upper Cretaceous weathering surface, which is caused by the preferential weathering of mudstone and sandstone Paleozoic units, controls the present drainage system. The recent weathering cycle is dominated by erosion, and in the central portions of the Golden Blocks area these processes have accentuated
Figure 8-4  A diagrammatic E-W cross section of the mineralized zone at the Aorangi Mine. The flow of water down the permeable fault zone and out into the valley has enhanced the zone of oxidation and thus increased the zone of supergene enrichment.
the antecedent topography of the Upper Cretaceous weathering surface. Outcrops of Pakawau Group sediments on the sides of Conns and Big Slaty Creeks suggest the removal of approximately thirty metres of Paleozoic rock by erosional processes since the deposition of the Pakawau Group. Conns Creek follows the sheared contact between Members AM₄ and A₁. Carbonaceous mudstones of Member A₁ represent a potential horizon of primary gold mineralization. However the lack of economic mineralized zones associated with this horizon is possibly a result of the following factors; 1. The low primary tenor of lodes and 2. the removal of enriched portions of lodes by recent erosional processes.

Similarly, the concentration of recent erosion along the contact of Members AM₃ and AM₄ in the vicinity of the Aorangi Mine may explain the lack of economic mineralization associated with favourable mudstone ore horizons in Member AM₃. Thus, the erosion of portions of enriched lodes associated with the exhumed Upper Cretaceous weathering surface may have played an important role in controlling the distribution of economic gold deposits in the Golden Blocks area.

V A MODEL OF GOLD DEPOSIT FORMATION IN THE GOLDEN BLOCKS AREA

Figure 8-5 presents a model of primary gold mineralization.
Primary Lode Deposition

_Caused_ by wall-rock interactions between carbonaceous mudstones and mineralizing solutions. _Confined_ to deformation zones permeable mineralizing solutions.

Source of Mineralization and Mineralizing Phases

Source of mineralization: Paleozoic Sediments

Derivation of Hydrothermal Phases
1. Metamorphic fluids.
2. Magmatic fluids.
3. Connate waters.

Movement of mineralizing solutions due to pressure gradients aided by tectonism.

Figure 8-5 Model of primary gold deposit formation in the GoldenBlocks Goldfield.
A Paleozoic metasediment source of gold and sulphides for mineralization in the Golden Blocks area is favoured by the author. Gold may have been selectively concentrated in sandstone units by sedimentary or diagenetic processes. Mineralization and hydrothermal activity is associated with Deformation Phase Four which is tentatively correlated with Tuhua Orogenic events. Hydrothermal phases responsible for the leaching and transport of ore minerals are considered to be derived from multiple sources. The movement of hydrothermal phases in the sequence of Paleozoic metasediments in the Golden Blocks area is mainly confined to deformation zones in sandstones. Pressure gradients are considered responsible for fluid movement.

In this area solution wall-rock interaction between hydrothermal phases and mudstones, especially carbonaceous mudstones, are regarded as the primary factor causing the concentration and deposition of ore minerals from hydrothermal phases. Because of the restricted movement of ore fluids in mudstones, primary mineralization is confined to particular horizons and structurally favourable zones.

The primary gold tenor of lodes in the Golden Blocks area is generally uneconomic and supergene solutions associated with the Upper Cretaceous weathering surface play a very important role in enhancing the primary tenor of the lodes to payable grades.
Figure 8-6 Geology of part of the Kahurangi Sheet (Bishop 1968). This shows the distribution of the favourable ore horizon, the Aorangi Mine Formation, to the west of the study area.
development and preservation of the Upper Cretaceous weathering surface controls the distribution of productive gold deposits in the Golden Blocks area.

VI GUIDES TO FUTURE PROSPECTING

The geology of a portion of the Kahurangi Sheet (Bishop 1968) is shown in Figure 8-6. Sediments of the Aorangi Mine and Sandhills Creek Formations form two belts, referred to as the eastern and western belts. Paleozoic sediments in the Golden Blocks area are associated with the eastern belt. On the basis of the stratigraphic position of auriferous lodes in the Golden Blocks area the mudstone units in the Sandhills Creek Formation and mudstone units near or at the contacts of this lithotype and sandstone units of the Aorangi Mine Formation are considered favourable horizons for primary gold mineralization. At most mine localities in this area supergene enrichment processes are responsible for enhancing primary gold values to economic grades. Thus, the primary targets for prospecting are intersection of favourable ore horizons with the Upper Cretaceous weathering surface. Because of the generally low primary tenor of lodes in this area the probability of finding economic deposits of primary gold mineralization is slight. Minor auriferous occurrences have been reported from the Aorangi Mine and Sandhills
Creek Formations to the west of the Golden Blocks area. At Independence Stream, a branch of Frazer Stream (Kahurangi Sheet S1 Bishop 1968 (820,955)) a small quantity of gold (100 oz) was won from quartz lodes (Newport 1970). Bishop (1968) reported a high copper anomaly near the junction of the north and south branches of the Anortori River. If the stratigraphy of the Aorangi Mine and Sandhills Creek Formations in the Western belt is similar to that in the Golden Blocks area further prospecting of Western Belt sediments is warranted especially where Paleozoic sediments are intersected by the Upper Cretaceous weathering surface.
RECOMMENDATIONS FOR FURTHER RESEARCH

1  SEDIMENTOLOGY AND DIAGENESIS OF PALEozoIC SEDIMENTS

The depositional environment of Paleozoic sediments in the Golden Blocks area was an aspect of the stratigraphy not studied. Although good exposures are generally confined to stream sections, a sufficient number of internal structures were observed to permit a sedimentological study of the environment of deposition. Such a study could evaluate the feasibility of erosional processes causing placer concentrations of gold in Paleozoic sediments of this area. A study of the diagenesis of Paleozoic sediments in this area may also contribute to an understanding of the role of pore fluid movement during diagenesis in the concentration of ore minerals.

2  STRUCTURE

The structure of Paleozoic sediments in the Golden Blocks area is complex, however, the abundance of various types of deformation structures allows the style and timing of deformation events to be determined. The structural relationships of the Aorere and Haupiri
Groups in the Nelson area are the subject of much controversy (Grindley (1971), Cooper (1975)). Haupiri Group sediments occur to the south and east of the Golden Blocks area and investigations of the style of deformation events in these sediments and their structural relationships to the younger Paleozoic sediments may assist in elucidating the character of early tectonic deformation in Paleozoic sediments of the Nelson area.

3 MINERALIZATION

The source of gold and hydrothermal phases responsible for the formation of hydrothermal quartz lodes in the Golden Blocks area are aspects which require further research. Oxygen and sulphur isotope studies of quartz veins and sulphides in this area could provide further evidence of the source of vein constituents. The timing of mineralization in relation to regional igneous and metamorphic events could not be unequivocally determined. Potassium-argon dating or similar procedures could be applied to the micas present in mineralized quartz lodes in order to determine the age of mineralization in relation to orogenic events in the north-west Nelson area. In the Golden Blocks area secondary mobilization of gold is considered very important in the formation of economic gold deposits. Further investigation of supergene enrichment processes is warranted.
Apparatus, preparation of samples, and methods used in the determination of fluid inclusion filling temperatures

The apparatus used in filling temperature determinations was a heating stage from a "Reichert" hot stage microscope, mounted on the rotating stage of a Leitz "Ortholux" polarizing microscope. This microscope was fitted with a long focus 44x objective and 20x binocular eyepieces. Magnifications of 1100x diameters are obtainable which permit the study of inclusions down to 2μm in size. A Variac transformer was used to control heating stage temperatures which were measured by a mercury thermometer. The heating stage and thermometer were calibrated by measuring the melting points of various crystalline solids. This method indicated that the accuracy of the thermometer in measuring the temperature of the heating stage was to within 1°C, using a final heating rate of 2°C per minute.

Initial sample preparation begins with the mounting of the specimen chip in Lakeside 70 on a glass slide. After grinding to thin section thickness the slide is placed in alcohol to dissolve the Lakeside 70 and allow removal of the specimen from the glass slide. Both sides of the specimen were polished using various
grades of diamond paste and given a final buffing, using tin oxide. During heating runs, the sample chip is mounted on a glass slide in high-temperature silicon oil and covered by a cover slip. Silicon oil is also smeared on the heating stage to ensure that the sample and glass slide are in thermal equilibrium with it. Cooling of the specimen by air currents was minimized by placing aluminium foil over the heating stage in which a suitable opening for the objective was provided.

The extremely small size of inclusions found in the Golden Blocks area presented problems in determining the exact temperature at which the gas bubble was homogenized. This problem was partially solved by using inclusions containing rapidly moving bubbles. Rapid bubble movement results in a blurring within the inclusion, the clearing of which, on heating, signals homogenization of the inclusion. Tubular shaped inclusions and negative crystal inclusions allow viewing throughout the inclusion without focus adjustment. As this allowed accurate determination of the homogenization temperature, these inclusions were used wherever possible. Using slow heating rates and the techniques described above, errors could generally be kept below 5°C during homogenization runs. Reruns were made to check the inclusion for leakage.
**APPENDIX II**

**Apparatus, sample preparation and methods used in the determination of inclusion fluid salinities**

A Leitz Ortholux polarizing microscope incorporating the same objectives and eye pieces as described in Appendix I was used during freezing point determinations. The cooling stage, which was mounted on the rotating stage of the microscope, was constructed from aluminium in two parts. Cooling fluids were circulated through cavities drilled in the upper plate, the centre of which was hollowed to allow positioning of the microscope objective close to the specimen. The specimen was placed over a hole in the bottom plate. This permitted illumination of the sample from below. The hollow plate also contained the thermometer. The two plates were clamped together with immersion oil smeared between the surfaces to ensure conduction between them and both plates were insulated with a polystyrene surround.

The cooling fluid (alcohol), was chilled by adding it to a vacuum flask partially filled with dry ice (solid carbon dioxide). Insulated plastic tubing connected the flask to the cooling stage. The addition of alcohol to dry ice produced copious quantities of carbon dioxide gas, the pressure of which was sufficient to drive chilled alcohol through the cooling stage and into a collecting
vessel. Further dry ice and alcohol were added when necessary.

The temperature of the cooling stage was measured by a red spirit thermometer positioned in a hole drilled near the top of the bottom plate. The cooling stage and thermometer were calibrated using solutions of known freezing points. Glass slides containing small droplets of these solutions were placed on the freezing stage. Immersion oil smeared between the glass slide and the cooling stage ensured thermal equilibrium between the two. The pumping mechanism, although crude, did allow a measure of control over the rate of cooling. When 50cc of alcohol was added to dry ice the stage was cooled by approximately 5° to 10°C within 2 to 4 minutes. However, the cooling stage gained heat from the atmosphere at a steady rate of 2°C per minute. The resultant slow cooling rate allowed precise observation of phase changes in test samples, and calibration runs indicated that the thermometer readings were accurate to within 1°C over a range of 0°C to -25°C. The lowest temperature obtainable with this apparatus was controlled by the extent to which the alcohol could be chilled; this was approximately -45°C. During cooling runs, temperatures were lowered in steps of approximately 5°C and this temperature was maintained for 5 minutes to allow the specimen to reach thermal equilibrium with the stage. The light source was switched off whenever possible
to prevent heating of the sample.

Samples were prepared in a similar manner to those used in homogenization experiments.
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