Structural Setting and Controls of Gold Mineralization

at the Macassa Mine,

Kirkland Lake, Ontario

By

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Abstract

The Macassa gold mine is located in northeastern Ontario, approximately 3 km west of the Town of Kirkland Lake. The mine produced more than 3.5 million ounces of gold between 1933 and 1999. The Macassa mine was one of seven major gold mines in the Kirkland Lake camp that collectively produced in excess of 24 million ounces of gold from an area stretching for approximately 7 km along strike, and to mining depths of 2.5 km.

The Macassa gold mine is located in the 2.75 to 2.67 billion-year-old Abitibi greenstone belt. The mine is underlain by sedimentary and volcanic rocks of the Archaean Timiskaming Group in a package several kilometres thick that flanks and is sub-parallel to the most significant structure in the area, the Kirkland Lake-Larder Lake break. Rocks of the Timiskaming Group unconformably overlie pre-Timiskaming volcanic rocks belonging to the Abitibi Supergroup, which include the Blake River Group volcanics, and the predominantly tholeiitic Kinojevis Group. Intruded into the Timiskaming sedimentary and volcanic rocks is a composite syenite stock with three main components consisting of augite syenite, felsic syenite, and syenite porphyry. The intrusive rocks have hosted most of the ore at the Macassa mine and throughout the Kirkland Lake gold camp.

The Macassa mine is a structurally controlled gold deposit. Structures controlled intrusion of the syenitic stocks, emplacement of the mineralising hydrothermal fluids, and post-ore displacement. Most of the gold mineralization in Kirkland Lake is associated with the Kirkland Lake break (Main break) fault-system, and associated sub-parallel structures. The Main break is most likely a local branch or splay of the regional Kirkland Lake-Larder Lake break. The sub-vertical, to steeply south-dipping, '04 break is the most important ore-related structure during the last two decades of mining at the Macassa Mine. The '04 break is located approximately 400 feet (122 m) north of the North branch of the Main break, and is connected through a series of cross-over faults that include the S and R breaks. Ore at Macassa consists of break-related ore, hangingwall and footwall veins and breccia ore. Other significant ore-related structures at Macassa include the '05 break (referred to as the Narrows break in the eastern mines of Kirkland Lake), and the 45-55° south-dipping No. 6 break. Post-ore faulting at Macassa occurs along major faults that include the '04 North break, the Tegren fault, and the Amikougami Creek fault.

Gold distribution in the Kirkland Lake gold camp demonstrates that the Lake Shore mine was situated near the centre of the gold-bearing system. The gold-bearing ore of Kirkland Lake has many characteristic components including the presence of telluride elements (chiefly altaite, calaverite, and coloradoite), and the occurrence of molybdenite along fine slips or minor faults on the margins of auriferous quartz veins.

A sequence of geological events for the formation of the Kirkland Lake ore has been proposed. The principal events include: early volcanism; basin formation; intrusion of alkaline intrusives; cooling of the intrusives; hydrothermal activity; mineralization; compressional deformation late in the ore-forming period; post-ore compressional deformation; and post-ore cross-faulting.

Several exploration targets have been developed for the Macassa mine. These include: specific prospective areas along the '04 break; mineralised structures to the south of the '04 break, including the No. 6 break; zones to the north of the '04 break, including the '05 or Narrows break; and prospective hangingwall and footwall veins.
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# Table of Contents

Abstract ii  
Acknowledgements iii  
Table of Contents iv  
List of Figures vii  
List of Tables ix  

Chapter 1: Introduction 1  
  Location 1  
  Purpose 1  
  Methodology 3  
  Previous Work 4  

Chapter 2: Regional Geological Setting 6  
  Geology of the Abitibi Greenstone Belt 6  
    i) Introduction 6  
    ii) Supracrustal Rocks 8  
    iii) Plutonic Rocks 10  
    iv) Structural Geology 10  
    v) Metamorphism 10  
    vi) Formation of the Abitibi Belt 11  
  Geology of the Kirkland Lake Camp 11  
  Kirkland Lake's "Mile of Gold" 18  
    Toburn 21  
    Sylvanite 22  
    Wright-Hargreaves 24  
    Lake Shore 28  
    Teck-Hughes 31  
    Kirkland Lake Gold 32  
    Macassa 34  

Chapter 3: Macassa Mine Geology 35  
  Introduction 35  
  Description of Host Rocks 36  
    A. Timiskaming Group 39  
      i) Conglomerate 39  
      ii) Greywacke 39  
      iii) Tuffs 41  
      iv) Trachyte 41  
    B. Intrusive Rocks 41  
      i) Augite (Basic) Syenite 41  
      ii) Felsic Syenite 42  
      iii) Syenite Porphyry 42
Chapter 6: Exploration at the Macassa Mine 126
 Characteristics of mineralised Material 126
 Exploration Targets at Macassa 129
 '04 Break Exploration 129
 Exploration South of the '04 Break 133
 Exploration North of the '04 Break 135
 Hangingwall and Footwall Veins 136

Chapter 7: Summary and Conclusions 141
 '04 Break 141
 '05 Break 142
 No. 6 Break 142
 Hangingwall Veins 142
 '04 North Break 143
 Amikougami Creek Fault 143
 Gold Distribution 144
 Summary of Principal Geological Events 144
 Implications for Exploration 144

References 146

VITA 151
List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1</td>
<td>Location map of Kirkland Lake, Ontario, Canada</td>
<td>2</td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>Location of the Abitibi Subprovince in the southeastern portion of the Superior Province</td>
<td>7</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Geological map of the Abitibi greenstone belt, showing major lithological units</td>
<td>9</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>Model for the formation of the Archaean continental crust in the southeastern Superior Province</td>
<td>12</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>Generalised geology of the Kirkland Lake camp</td>
<td>13</td>
</tr>
<tr>
<td>Figure 2.5</td>
<td>Sinistral strike-slip fault showing features that cause subsidence and/or sedimentation</td>
<td>16</td>
</tr>
<tr>
<td>Figure 2.6</td>
<td>Longitudinal view of the Kirkland Lake camp looking to the north on the '04 break / Main break plane</td>
<td>19</td>
</tr>
<tr>
<td>Figure 2.7</td>
<td>North-south cross-section through the Sylvanite Mine looking east</td>
<td>23</td>
</tr>
<tr>
<td>Figure 2.8</td>
<td>Plan view of the structural geology of the Lake Shore and Wright-Hargreaves mines from the 600 foot-level</td>
<td>25</td>
</tr>
<tr>
<td>Figure 2.9</td>
<td>North-south geological section through the Wright-Hargreaves mine showing the nature of the numerous flat-dipping post-ore faults</td>
<td>27</td>
</tr>
<tr>
<td>Figure 2.10</td>
<td>Longitudinal sections showing the distribution of the ore on the South (No. 1) vein and the North (No. 2) vein at the Lake Shore mine</td>
<td>30</td>
</tr>
<tr>
<td>Figure 2.11</td>
<td>North-south section through Kirkland Minerals (Kirkland Lake Gold) showing the Kirkland Lake fault (Main break), the No. 6 break, and the No. 5 vein</td>
<td>33</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>Milling statistics for the Macassa Mine, 1933-1999</td>
<td>38</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>Level plan of the 6050' Level in the Macassa Mine</td>
<td>40</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>Plan of part of the 4750' Level illustrating break relationships and associated veining</td>
<td>45</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>Cross-section looking east along section 31450 through the Macassa Mine</td>
<td>53</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>East face of the 4729.32 Sub No. 2 ('04 Break)</td>
<td>54</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Composite image of the 7038.50 PUC, facing east</td>
<td>56</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>View of the 7038.50 PUC stope, facing west</td>
<td>57</td>
</tr>
<tr>
<td>Figure 4.5</td>
<td>Plan view of the 6733 area showing a wide zone of breccia ore footwall to the '04 break</td>
<td>58</td>
</tr>
<tr>
<td>Figure 4.6</td>
<td>Photomicrograph of the '04 Break from the 4711 area</td>
<td>60</td>
</tr>
<tr>
<td>Figure 4.7</td>
<td>4729.32 Sub No. 2. Intermineral dyke injected between a massive quartz vein located in the hangingwall of the '04 break</td>
<td>61</td>
</tr>
<tr>
<td>Figure 4.8</td>
<td>Cross-section facing east through the macassa Mine showing the '04 break and Main break</td>
<td>63</td>
</tr>
<tr>
<td>Figure 4.9</td>
<td>Two photographs illustrating the varying nature of the '05 break</td>
<td>65</td>
</tr>
<tr>
<td>Figure 4.10</td>
<td>Geological mapping of the '05 break zone from the 6635.39 Sub No. 3</td>
<td>67</td>
</tr>
<tr>
<td>Figure 4.11</td>
<td>Longitudinal section of the '05 break looking to the north</td>
<td>69</td>
</tr>
<tr>
<td>Figure 4.12</td>
<td>Polished slab of the '05 break, from the 6635.39 sub 4</td>
<td>71</td>
</tr>
</tbody>
</table>
Figure 4.13 Schematic sketch of pebbles in conglomerate from the 7035.39
Sub No. 4 in the immediate footwall of the '05 break ................................. 72
Figure 4.14 Photos illustrating post-ore deformation along the '05 break .......... 73
Figure 4.15 Illustration of post-ore cross-faulting along the backs of the 6635.39
Sub No. 3 ........................................................................................................ 74
Figure 4.16 Idealised cross-section of the Macassa Mine facing east at section 30W .... 76
Figure 4.17 Preliminary reserve longitudinal section of the the 4529.37 No. 6
break block, looking to the north. ................................................................. 78
Figure 4.18 Plan view of the 5600' level showing the '04 break, South break, and
crossover faults .......................................................................................... 85
Figure 4.19 Three-dimensional view looking to the northeast of the 4719 complex .... 89
Figure 4.20 Photomicrograph of the S3 hangingwall vein from the 4250 Level 91
Figure 4.21 Various forms of hangingwall quartz veining at Macassa .......... 92
Figure 4.22 4518.37 stope, facing west. .......................................................... 93
Figure 4.23 Sketch of the backs in the 4206 stope area showing folded quartz
veining at the intersection of the S1 and S3 veins ........................................ 96
Figure 4.24 Photograph of the 4520.37 vein, facing east ................................. 97
Figure 4.25 Idealised cross-sections showing displacement of the '04 break by
the '04 North break from sections 40W to 20W ............................................. 100
Figure 4.26 Idealised cross-sections showing displacement of the '04 break by
the '04 North break from sections 15 W to 10E ............................................. 101
Figure 4.27 Nature of the '04 North break at Macassa mine ...................... 103
Figure 4.28 Exposure of the '04 North break encountered during 6934 stope ore
development, west face ............................................................................ 105
Figure 4.29 Quartz stringer in basic syenite in the immediate footwall of the
'04 North break ............................................................................................ 106
Figure 4.30 Geological mapping of the '04 break, the '04 North break, and the
North break from the 6934 area ................................................................. 108
Figure 4.31 Cross-section looking west, showing the relationships of the various
faults in the 6934 area along the line A-B .................................................... 109
Figure 4.32 View of the Tegren cross-fault from the backs of the 6934 FWD .... 111
Figure 5.1 Schematic longitudinal view of the Kirkland Lake camp looking to the
north on the '04 break / Main break plane. Each symbolic bar of gold
represents 100,000 ounces mined ................................................................. 117
Figure 6.1 Grade contours at the Macassa mine along the '04 break, projected
onto a longitudinal section looking 32°30' west of north ........................ 131
Figure 6.2 Contours of horizontal widths of mineralised material (>0.25 oz/t)
at the Macassa mine along the '04 break, projected onto a longitudinal
section looking 32°30' west of north .......................................................... 132
Figure 6.3 Geological cross-section through the Kirkland Minerals mine
showing the series of hangingwall veins located between the Kirkland Lake
fault (Main break) and the No. 6 break ........................................................ 137
Figure 6.4 Composite cross-section through the Macassa mine at section
25+50W looking east .............................................................................. 138

viii
List of Tables

Table 2.1 Comparison of characteristics of strike-slip mobile belts......................... 15
Table 2.2 Production statistics for the major producing mines of Kirkland Lake......... 20
Table 3.1 Macassa Mine production statistics, 1933-1999........................................ 37
Table 3.2 Mineralogy of the Kirkland Lake ores, from Hawley (1950).......................... 48
Table 4.1 Calculated displacements along the major faults of Kirkland Lake.............. 51
Table 4.2 Tabulation of the 1999 Macassa Mine reserves by mineralization type........ 87
Table 5.1 Gold distribution within the gold mines of Kirkland Lake......................... 119
Chapter One
Introduction

Location

The Macassa gold mine is located in northeastern Ontario, approximately 3 km west of the Town of Kirkland Lake (latitude 48° 09' North, longitude 80°03' West) (Figure 1.1). The Kirkland Lake gold camp is within the Abitibi greenstone belt which hosts other prolific mining camps such as Timmins, Rouyn-Noranda, Larder Lake, and Val d’Or.

The Macassa mine is the westernmost of the seven major past producing mines of the Kirkland Lake camp. From west to east, the mines of Kirkland Lake are Macassa, Kirkland Lake gold, Teck-Hughes, Lake Shore, Wright-Hargreaves, Sylvanite, and Toburn (Figure 2.4). Collectively these mines have produced over 24 million ounces of gold since the initial discovery on surface in 1911. The discovery claim would later become the Wright-Hargreaves Mine. The high-grade Archaean lode gold ore has allowed the mines to maintain an average head grade near 0.50 oz/t over most of their histories.

The Macassa mine and adjacent mine property is currently owned and operated by the Kinross Gold Corporation. On June 12, 1999 all underground operations and exploration at Macassa were suspended indefinitely due to low gold prices. Until this point, Kinross was aggressively exploring for additional reserves along existing and untested structures in order to continue the long and rich mining history in the area.

Purpose

The primary objective of this study is a compilation of structural data in the Macassa gold mine. Areas covered in most detail are those that have seen little or no description in previous reports, and areas of the most recent or current mining and/or exploration. The structural model based on these data will be used to infer the timing and controls of gold deposition and generate new targets for exploration. The targets may be used to support and expand future exploration initiatives at the mine and to identify and
Figure 1.1. Location map of Kirkland Lake, Ontario, Canada.
quantify additional reserves in the Kirkland Lake area. At the time operations were suspended, exploration efforts were primarily aimed at maintaining and increasing mineable reserves using existing Macassa infrastructure.

Methodology

Research of the writer on the structural complexities of the Macassa mine began in May 1996 while working as a project geologist at the minesite. Until April 1997, the work was based on direct underground geological observations of active and inactive headings. Excellent underground exposure at all levels of the mine from the 4 250' level (see author's note at the end of this chapter) to the 7 050' level was gained through sampling active headings and mapping of development drifts and sub-levels in waste and ore-bearing areas. Time was also spent completing detailed geological logs of underground definition and exploration diamond drill holes. This direct exposure to the geology of the mine on a variety of different scales was essential to gain a detailed understanding of the structures of the mine and how they relate to ore-bearing zones.

On April 12, 1997, a series of powerful rockbursts at the Macassa mine damaged the main production shaft (#3 shaft) near the 5 800' elevation, and underground operations were temporarily suspended. When underground production re-commenced several months later, only the upper levels of the mine from the 4 250' to 5 000' levels were accessible, and subsequent research focused on the upper portion of the mine. In July 1997, the writer's duties at the mine switched to exploration, which allowed the previous year's observations and hypotheses to be tested and implemented in the search for additional reserves through extensive diamond drilling programs.

Compilation of observations at Macassa continued into 1998 while working as an exploration geologist and then, from March 1998 to July 1999, as Senior Geologist. During 1998, a leave of absence was granted by Kinross Gold Corporation that allowed the writer to return to Queen's University to complete research on this thesis. The final compilation and presentation of data was prepared from 1999 to 2001, after operations at Macassa were suspended.
Previous work

Numerous studies have been completed in the Kirkland Lake area since the original discovery of gold in 1911. Most of the gold mined in the Kirkland Lake camp has come from mines situated on or adjacent to the Kirkland Lake Fault (also known as the Main break) (Figure 2.4 and subsequent chapter on the regional geological setting). This fault is most likely a local branch or splay of the regional Kirkland Lake – Larder Lake break. The first structural study of the Kirkland Lake fault was completed in the 1920’s by Tyrell and Hore (1926). A more comprehensive study was completed by Todd (1928) who detailed the structure and nature of mineralised zones with emphasis on portions of the Main break. The next major work on the Kirkland Lake camp, by Thomson (1950) and Thomson et al., (1950), served as an invaluable reference on the Kirkland Lake camp for close to 50 years. It details the geology of the main ore zone at Kirkland Lake with an emphasis on structural geology and mineralogy of the gold ores. The geology of the seven major producing mines of the camp is discussed.

The classic work of Thomson et al., (1950) was followed up by Charlewood (1964) who updated the previous work and detailed the geology of deep developments on the main ore zone at Kirkland Lake. Since then, many of the geological reports and studies on the Kirkland Lake camp have been specific to certain aspects of the regional geology. The topics included studies on metamorphism by Jolly (1978); the relationship between gold and syenitic intrusive rocks by Ploeger and Crocket (1982); the nature of Timiskaming volcanics and sediments by Cooke (1966), Cooke and Moorhouse (1969), Goodwin (1965), Hewitt (1963), Ridler (1969, 1970, 1975, 1976), Hyde and Walker (1977), and Jensen (1978); geochronological studies by Corfu et al., (1991) and Corfu (1993); and the mineralization of the area by Cameron (1993).

Other studies have focused on specific areas of interest such as sedimentary studies by Mueller et al., (1992, 1994); studies of local plutonic rocks by Cruden (1992), and Rowins et al., (1993); regional structural geology by Hopkins (1949), Toogood and Hodgson (1985), Cameron (1990), and Hodgson et al., (1990); and a detailed study of the alkaline tuffs of the Timiskaming Formation by Lackey (1990).

Several recent studies are specific to the Macassa mine (e.g. Cater, 1995; and an

*Author's Note*: Due to the lengthy history of the Macassa Mine, all measurements within the mine are reported in Imperial units. In order to have this thesis consistent with current mine documents, all standard procedures for reporting measurements within the mine are maintained. All levels within the mine are referenced in feet below surface and all gold assays are reported in Troy ounces per short ton. The following conversion factors can be applied to produce Metric equivalents:

1 foot = 0.3048 metres
1 Troy ounce = 31.1035 grams
1 oz/ton = 34.29 g/tonne
Chapter Two
Regional Geological Setting

Geology of the Abitibi Greenstone Belt

i) Introduction

Kirkland Lake is located in the 2.75 to 2.67 billion-year-old Abitibi greenstone belt, which is the world's largest greenstone belt covering an area of roughly 85,000 km² in north-eastern Ontario and north-western Quebec (Card, 1990; Jackson and Fyon, 1991; Spooner and Barrie, 1993: see Figure 2.1). The Abitibi belt is part of the larger Abitibi Subprovince, a granite-greenstone-gneiss terrane that is located within the south-eastern portion of the Archaean Superior Province (see Figure 2.1). The western part of the Abitibi Subprovince is bound in the north by para- and orthogneisses of the Opatia Subprovince; in the east by the faults and cataclastic zones of the Grenville Front Tectonic Zone; in the south-east by a fault contact with Archaean metasediments of the Pontiac Subprovince; in the south-west by unconformably overlying sediments of the Huronian Supergroup and Keweenawan volcanics and sediments; and in the west by the Kapuskasing Structural Zone (Card, 1990: Figure 2.1).

Although outcrop in the Abitibi greenstone belt is generally limited as the result of a till and clay cover, locally over 30 m thick, exposure in the Kirkland Lake camp is quite good, leading to the first discovery of gold in a surface outcrop in 1911. Surface mapping in the Abitibi Subprovince has been supplemented by geophysical surveys (i.e. GSC 1:500 000 colour magnetic and gravity surveys, 1996) showing negative magnetic and positive gravity expressions in areas where the surface geology consists of greenstone belts and tonalitic plutons, and positive magnetic and negative gravity anomalies in areas of granitic plutons (Card, 1990).

The geology of the western Abitibi Subprovince in Ontario has been summarised by Jackson and Fyon (1991). Volcanic rocks formed between 2.75 and 2.70 Ga in ensimatic oceanic settings. These rocks were subsequently metamorphosed, however, the prefix meta- has been omitted from all units for the purpose of simplification. The metavolcanic rocks range from komatiitic and tholeiitic to calc-alkaline. Between 2.70 and 2.68 Ga, turbidite-dominated assemblages formed.
Figure 2.1. Location of the Abitibi Subprovince in the southeastern portion of the Superior Province. The arrow indicates the location of Kirkland Lake (from Jackson and Fyon, 1991).
This was followed by alkaline volcanic rocks and intrusion associated fluvial sedimentary rocks between 2.68 and 2.67 Ga. Three main divisions of granitoid intrusive rocks exist. Tonalite-trondhjemite-granodiorite batholiths formed between 2.74 to 2.69 Ga; smaller granodiorite intrusives formed between 2.70 to 2.68 Ga; and syenite stocks formed between 2.69 to 2.67 Ga.

ii) Supracrustal Rocks

A simplified geological map of the Abitibi greenstone belt (Figure 2.2) shows that about 80% of the Abitibi belt is composed of volcanics and related intrusions, whereas metasediments compose the remaining 20% (Card, 1990). Within volcanic sequences, about 70% are tholeiitic and 25% are calc-alkaline with minor komatiitic and alkalic sequences (Card, 1990). In the southern Abitibi belt, Goodwin (1977) estimated that volcanic sequences consist of 55% basalt, 34% andesite, 7% dacite, and 4% rhyolite.

The supracrustal rocks have been described by Jackson and Fyon (1991) and were subdivided into the following assemblage types:

1) komatiite-tholeiite-dominated assemblages with interflow iron formation;
2) komatiite and/or tholeiite-dominated assemblages with significant felsic metavolcanic rock;
3) komatiite-tholeiite-dominated assemblages without significant iron formation or felsic metavolcanic rocks;
4) tholeiite-dominated assemblages characterised by alternating magnesium- and iron-rich units;
5) tholeiite-dominated assemblages containing thick units of either iron- or magnesium-rich units, or both;
6) ultramafic to mafic and felsic metavolcanic rocks associated with iron formation;
7) intermediate to felsic metavolcanic, fragmental rock-dominated assemblages;
8) intermediate effusive metavolcanic assemblages;
9) turbiditic metasedimentary-dominated assemblages; and
10) alluvial-fluvial metasedimentary and alkalic metavolcanic-dominated assemblages (Timiskaming-like assemblages).

“Most of the metavolcanic assemblages are between 2720 and 2700 Ma; however, some are 2750 to 2720 Ma and, at least locally, form stratigraphic and/or structural basement to the younger assemblages. The alluvial-fluvial metasedimentary assemblages locally rest unconformably on top of the metavolcanic-dominated assemblages and the turbidite-dominated metasedimentary assemblages. Contacts between other assemblages are either unknown or they are faults.” (p. 405).
Figure 2.2. Geological map of the Abitibi greenstone belt, showing major lithological units (modified from Mueller and Donaldson, 1992).
Many major gold deposits in the Abitibi belt are spatially related to Timiskaming assemblages as evidenced by their occurrences in Timmins-Porcupine, Kirkland Lake, Val-d'Or, Noranda, Larder Lake, Duparquet, and Chibougamau (Mueller and Donaldson, 1992).

iii) Plutonic Rocks

Plutonic rocks that are 2.74 to 2.69 billion-years-old form batholithic complexes of early, pre-kinematic tonalite gneiss which are found within and surrounding the Abitibi belt (Card, 1990). Numerous 2.70 to 2.68 billion-year-old pre- to synkinematic plutons of quartz diorite, tonalite, and granodiorite form the cores of central volcanic complexes. Many late- to post-kinematic intrusions, most commonly granodioritic or monzogranitic in composition, cut structural trends and commonly have amphibolite facies metamorphic aureoles (Card, 1990). Syenitic and other 2.69 to 2.67 billion-year-old alkalic rocks are intruded into younger, Timiskaming-type supracrustal rocks in several locations, most notably in the Kirkland Lake area (Cameron, 1990).

iv) Structural Geology

The regional structural setting in the Abitibi Subprovince has been summarised by Jackson and Fyon (1991). Within the subprovince most penetrative fabrics and structures in supracrustal rocks are domainal and parallel regional faults and assemblage boundaries. Thrust faults, “pre-cleavage” folds, and structures associated with batholith emplacement (2.74 to 2.69 Ga) predate the synmetamorphic overprint. Folding and regional shear zones formed during and after emplacement of batholiths. Steep reverse faults and/or thrust faults were also formed during this period. The structures are compatible with having resulted from a north-south compressional regime.

Late, brittle faults related to the formation of the Paleoproterozoic Cobalt Embayment and the Phanerozoic Timiskaming Rift overprint earlier Archaean structures. The Archaean structures generally strike west, northwest to west-northwest, and northeast to east-northeast, whereas the late structures strike northeast, northwest, and north-northeast.

v) Metamorphism

The metamorphic grade of the Abitibi belt is generally very low (Card, 1990). Most of the belt is in the lower greenschist facies, and significant areas are in
subgreenschist, prehnite-pumpellyite facies. Higher grade metamorphic rocks occur in contact metamorphic aureoles around granitic intrusions where grades of upper greenschist and lower amphibolite or hornblende hornfels facies may be reached. Structures associated with early batholith emplacement (2.74 to 2.69 Ga) are overprinted with synmetamorphic folding and regional shear zones that formed after batholith emplacement.

vi) Formation of the Abitibi Belt

It is now widely accepted that the Abitibi Subprovince formed as the result of Archaean subduction-related accretion against a pre-existing protocraton in the north (Card, 1990; Hoffman, 1991; Jackson and Cruden, 1995; Calvert and Ludden, 1999). Calvert and Ludden (1999) explain the formation of portions of the Superior Province using recent LITHOPROBE seismic reflection and refraction surveys. Evidence presented is used to support a model for the formation of the continental crust of the southeastern Superior Province in the late Archaean through terrain accretion along one or more prograding northward subduction zones. The Opatica plutonic belt developed as a volcanic arc against which the terrains of the Abitibi plate were accreted (see Figure 2.3). The geology of the Kirkland Lake area fits well with this model of: A) Arc and oceanic plateau formation; B) Terrain accretion and Opatica Orogen; C) Terminal collision; and D) Extension and subsequent lower crustal modification.

Geology of the Kirkland Lake Camp

The geology of the Kirkland Lake area has been described in a number of key papers (Todd, 1928; Thomson et al., 1950; Jensen, 1976) and is well summarised by Lackey (1990). To the north of Kirkland Lake are the tholeiitic volcanic rocks of the Kinojevis Group. Further north are the calc-alkaline volcanic rocks of the Blake River Group. To the south of Kirkland Lake are the komatiitic volcanic rocks of the Larder Lake Group. The Kinojevis Group volcanics to the north are unconformably overlain by alkaline volcanic and sedimentary rocks of the Timiskaming Group (Figure 2.4). To the south, the contact between Timiskaming and Larder Lake Groups is along the Kirkland Lake – Larder Lake break, a major regional fault described in subsequent paragraphs. The Timiskaming Group consists of alluvial - fluvial conglomerates and sandstones.
I. Arc and Oceanic Plateau Formation

II. Terrain Accretion and Opatica Orogen

III. Terminal Collision

IV. Extension and Subsequent Lower Crustal Modification

Figure 2.3. Model for the formation of the Archaean continental crust in the southeastern Superior Province. The cartoon shows the primary processes in the formation of the continental crust above the north-dipping subduction zone identified by seismic profiles (from Calvert and Ludden, 1999)
Figure 2.4. Generalised geology of the Kirkland Lake camp (modified from Kinross files).
(Mueller and Donaldson, 1992). trachytic alkaline lava flows, and pyroclastic tuff units (Lackey, 1990). The conglomerates of the Timiskaming assemblages contain distinctive red chert (jasper) clasts. Earlier structural studies have shown that the Timiskaming rocks are part of the north limb of a syncline (Thomson et al., 1950).

Recent models have suggested that Timiskaming assemblages are similar in structure and sedimentology to sequences which have been deposited in modern strike-slip basins (Table 2.1; Christie-Black and Biddle, 1985; Cameron, 1990; Mueller and Donaldson, 1992). The belt of Timiskaming rocks is thought to have been deposited in a strike-slip basin that strikes about 065° and is up to 5 km in width. The Kirkland Lake – Larder Lake break had sufficient strike-slip movements to cause uplift and/or subsidence along various sections of the fault. Where the fault was curved, there could have been subsidence along releasing bends and uplift at restraining bends (Figure 2.5).

For formation of the Timiskaming assemblage at Kirkland Lake, the first stage of the cycle was transtension, which led to basin formation and sedimentation. The extensional basin that formed was characterised by rapid subsidence and rapid facies change. This stage was followed by a transpressional stage where the sediments were uplifted and folded.

Volcanism is not commonly present in all pull-apart basins, but where it has been observed, the rocks are of alkaline composition. This generation of alkaline magmas has been related to the adiabatic rise of the mantle caused by extension (Cameron, 1993). Partial melting of carbonated peridotite generated the alkaline magmas and CO₂-rich fluid which may have acted as the base for the solvent that carried the gold.

The Timiskaming sediments are intruded by numerous elongate alkaline intrusions. These consist of alkali-feldspar syenite and lamprophyre as well as quartz-monzonite (feldspar porphyry) (Levesque et al., 1991). In general terms, these units are known as feldspar porphyry (or syenite porphyry; Thomson, 1950), as it is difficult to estimate modal percentages of primary plagioclase and alkali feldspar in the ground mass (Levesque et al., 1991).

South of the Timiskaming sediments are a series of alkali-feldspar syenite and quartz-monzonite (feldspar porphyry) plutons such as the Otto and Murdoch Creek Stocks (Figure 2.4). Another pluton, the Lebel Stock is entirely syenitic (Levesque et al.,
<table>
<thead>
<tr>
<th>CHARACTERISTICS OF STRIKE-SLIP MOBILE BELTS</th>
<th>TIMISKAMING GROUP, KIRKLAND LAKE – LARDER LAKE FAULT ZONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrestrial Sedimentation</td>
<td>Braided river, floodplain, and eolian deposits;</td>
</tr>
<tr>
<td></td>
<td>conglomerate units up to 1 300 m thick.</td>
</tr>
<tr>
<td>Marine Sedimentation</td>
<td>Thick proximal turbidite, conglomerates; probably</td>
</tr>
<tr>
<td></td>
<td>deposited in a submarine fan.</td>
</tr>
<tr>
<td>Facies Change</td>
<td>Rapid local facies change; e.g., alluvial fan/fluvial</td>
</tr>
<tr>
<td></td>
<td>sediments to turbidites, all in less than 25 km.</td>
</tr>
<tr>
<td>Stratigraphic Thickness</td>
<td>3.5 km thickness in basin of 5 km width.</td>
</tr>
<tr>
<td>Metamorphism</td>
<td>Less than sub-greenschist.</td>
</tr>
<tr>
<td>Volcanism</td>
<td>Alkaline flows and pyroclastic deposits.</td>
</tr>
<tr>
<td>Faulting During Transstension</td>
<td>Normal faults and extensional fractures.</td>
</tr>
<tr>
<td></td>
<td>Normal faults?; alkaline intrusions in extensional</td>
</tr>
<tr>
<td></td>
<td>fractures.</td>
</tr>
<tr>
<td>Faulting During Transstension</td>
<td>Reverse, thrust.</td>
</tr>
<tr>
<td></td>
<td>Reverse faults. Thrusts?</td>
</tr>
</tbody>
</table>

Table 2.1. Comparison of characteristics of strike-slip mobile belts with Timiskaming Group, Kirkland Lake – Larder Lake fault zone (from Cameron, 1990).
Figure 2.5. Sinistral strike-slip fault showing features that cause subsidence and/or sedimentation (from Cameron, 1990).
The key structural feature within the Kirkland Lake camp is a major regional fault, the Kirkland Lake - Larder Lake break, which has been traced for over 300 km along strike. It strikes east-west and has been traced to the east through the Larder Lake-Virginiatown area (Kerr-Addison Mine) and into Quebec through Rouyn-Noranda, Cadillac and Val d'Or, until it terminates near Louvicourt at the Grenville Front. This eastern part of the fault is known as the Larder Lake-Cadillac fault. The Kirkland Lake-Larder Lake Break continues westward under Huronian sediments and appears in the Matachewan area some 50 km away (Powell, 1994). The break is a broad zone of "intense shearing, frequently accompanied by silicification and carbonatization" that represents the southern faulted contact between the Timiskaming sediments and the Larder Lake Group volcanics. The strongly sheared fault zone averages almost 60 m (~200 feet) in width but can be up to 210 m (~700 feet) wide in some locations near Larder Lake. Characteristic green fuchsite is commonly associated with the fault zone and is mined locally in large panels as a decorative stone. The fault is of a sinuous nature and dips sub-vertically. It dips steeply to the north, east of the Ontario-Quebec border, but dips steeply to the south, west of the Virginiatown area. A subvertical stretching lineation and sub-vertical schistosity are characteristic of the fault in the Kirkland Lake-Larder Lake area. According to Robert (1989) this suggests that the fault developed with mainly vertical movement and then evolved into a dextral transcurrent fault in a transpressive environment.

Mineralization in the Kirkland Lake camp is intimately associated with the Kirkland Lake break (Main Break) which strikes on average 067° and dips steeply to the south at 75°. This fault is most likely a local branch or splay of the regional Kirkland Lake - Larder Lake break. The Main break and various related branches and splays host most of the gold mineralization in the camp in quartz-rich zones adjacent to the faults and in related hangingwall and footwall veins.

At the east end of the camp, an increasing number of branches splay off the strong main branch (Thomson, 1950; Figure 2.5). These faults act to dissipate and lessen overall fault displacement which, based on pre-ore lithological relationships, is of a thrusting nature (south side up). The overall displacement is rotational and has been calculated to
be near 450 m (1500 feet) at the west end of the camp, and near 110 m (350 feet) at the east end (Thomson, 1950). To the west end of the camp, a fault sub-parallel to the Main Break, known as the ‘04 break, hosts most of the ore at the Macassa Mine.

Later cross-faults have displaced the various rock types, structures, and mineralization in Kirkland Lake (Figure 2.4). The two most significant of these late faults are the Amikoumagami Creek Fault and the Lake Shore Fault. Both faults strike near north-south, are sub-vertical, and have horizontal sinistral offsets of several hundred feet (over 100 m). The vertical displacement on these faults is not well known.

**Kirkland Lake’s “Mile of Gold”**

Seven major underground mines have produced gold in Kirkland Lake. All are located along a continuous stretch of the Kirkland Lake “break” (locally known as the Main Break) and related subsidiary zones. From west to east these mines are Macassa, Kirkland Lake Gold, Teck-Hughes, Lake Shore, Wright-Hargreaves, Sylvanite, and Toburn (see Figure 2.6). The first of these mines to enter production was the Tough-Oakes Burnside (later known as Toburn) which began milling in 1915 and was followed by Teck-Hughes (1917), Lake Shore (1918), Kirkland Lake Gold (1919), Wright-Hargreaves (1921), Sylvanite (1927), and Macassa (1933) (Thomson et al., 1950). Macassa was the last of the mines to close when production was suspended indefinitely in June 1999 as a result of low gold prices (near $250 U.S. per oz.).

The seven mines collectively produced in excess of 24 million ounces of gold and over 4 million ounces of silver from an area stretching for about 7 km along strike, and from surface down to the deepest workings in the camp, the 8 100' level (2469 m) at Wright-Hargreaves. Production statistics form the mines are shown in Table 2.2. Peak production from the camp came during the periods between 1931 and 1941, when in each of these years combined annual production exceeded 1.5 million tons (Thomson et al., 1950). The historical head grade of the Kirkland Lake camp is near 0.50 oz/t (Table 2.2).

The post-World War II years saw the beginning of the decline of the great gold mines of Kirkland Lake due primarily to the fixed price of gold ($35 per ounce), increased production costs, and depletion of easily accessible ore (Charlewood, 1964).
Figure 2.6. Longitudinal view of the Kirkland Lake camp looking to the north on the '04 break / Main break plane (modified by the author from Kinross files).
GOLD MINES OF KIRKLAND LAKE

<table>
<thead>
<tr>
<th>Mine</th>
<th>Dates of Operation</th>
<th>Gold Produced (Ounces)</th>
<th>Calc. Head Grade (oz/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Shore</td>
<td>1918 - 1965</td>
<td>8,499,199</td>
<td>0.51</td>
</tr>
<tr>
<td>Wright-Hargreaves</td>
<td>1921 - 1965</td>
<td>4,817,680</td>
<td>0.49</td>
</tr>
<tr>
<td>Teck-Hughes</td>
<td>1917 - 1968</td>
<td>3,688,664</td>
<td>0.38</td>
</tr>
<tr>
<td>Macassa</td>
<td>1933 - 1999</td>
<td>3,540,601</td>
<td>0.45</td>
</tr>
<tr>
<td>Sylvanite</td>
<td>1927 - 1961</td>
<td>1,667,520</td>
<td>0.33</td>
</tr>
<tr>
<td>Kirkland Lake Gold</td>
<td>1919 - 1960</td>
<td>1,172,955</td>
<td>0.37</td>
</tr>
<tr>
<td>Toburn</td>
<td>1915 - 1953</td>
<td>570,659</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Table 2.2. Production statistics for the major producing mines of Kirkland Lake.
The Toburn was the first mine to cease production in 1953 and was followed by Kirkland Lake Gold in 1960, Sylvanite in 1961, Lake Shore in 1965 (however underground mining of the crown pillar was conducted by Lac Minerals Ltd., in the mid 1980’s and surface mining of the crown pillars was conducted by Kinross Gold Corp. in 1997 and 1998), Wright-Hargreaves in 1965 (with Kinross Gold Corp. also mining portions of the crown pillar from surface in 1997 and 1998), and Teck-Hughes in 1968. Underground operations at Macassa were suspended indefinitely in June 1999.

Each of the seven mines on the “Mile of Gold” in Kirkland Lake is described in detail by Thomson et al., (1950), and Charlewood (1964). A brief summary of the geology of these mines has been prepared for this chapter.

**Toburn**

The Toburn mine is located on the eastern margin of the Kirkland Lake camp, bounded to the west by the Sylvanite mine. Originally the property was known as the Tough-Oakes Burnside mine which was discovered in 1912 and became the first producing mine in the Kirkland Lake camp. In 1931, Toburn Gold Mines Limited acquired the property and continued production until 1953. The mine was also the first to cease operations. In total, the mine produced 570 659 ounces of gold at a grade of 0.48 oz/t, making it the smallest gold producer in the camp. Today the Toburn headframe is one of the most recognisable features of Kirkland Lake. Flow-through money in the 1980’s was used for a distinctive red siding which adorns the headframe located on the east end of the town and provides a vivid reminder of the Town’s rich mining heritage.

The Toburn mine is located on the main syenite porphyry stock of the Kirkland Lake camp that plunges steeply to the west into the Sylvanite property. The deepest level is the 2 475 foot (754 m) level, making it the shallowest mine in the camp. Exploration line drives were extended from the adjacent Sylvanite mine on the 3 750 (1 143 m) and 5 550 (1 692 m) foot levels in 1950 and 1956 respectively. Exploration diamond drilling from these drifts failed to discover any ore.

Much like in the other mines in the camp, the Kirkland Lake fault (Main break) is the most persistent structure on the property, although it contains substantially less ore than the neighbouring Wright-Hargreaves and Sylvanite mines. The structure is known as
is a fracture system with highly variable southerly dips which reaches a maximum width of 1500 feet (457 m). One of the strongest of these structures is the North Branch vein which lies about 200 feet (61 m) to the north of the South vein and diverges at about 20 degrees east. The North vein extends across the property from the Wright-Hargreaves and Sylvanite mines, however displacement on this mineralised fault dies out on the Wright-Hargreaves property. On the Toburn side of the property boundary it is a general zone of fracturing with much less ore. The fracture system and hangingwall veins between the North vein and the South vein form a general zone similar to vein systems at the west end of the camp. Vein widths are generally less than 8 inches (20 cm) with over half of the ore-bearing veins hosted in syenite porphyry. The rest occurs in Timiskaming conglomerate, greywacke, and tuff. No ore has been found in basic syenite.

**Sylvanite**

The Sylvanite mine is located at the eastern end of the Kirkland Lake camp to the east of the Wright-Hargreaves mine and to the west of the Toburn mine. Production began in 1927 and was continuous until the mine closed in August 1961. During this period, the mine produced 1667 520 ounces of gold at a grade of 0.33 oz/t, ranking it fifth and seventh, respectively, in terms of ounces produced and grade of the seven mines of Kirkland Lake (Table 2.2).

As with other mines in the Kirkland Lake camp, the Kirkland Lake fault is the strongest and most continuous break in the mine. It extends across the southern portion of the property and dips steeply to the south from surface to below the 3000 foot (914 m) level. Below this the dip changes to the north and the fault is intersected and offset by the No. 5 strike fault (Figure 2.7). The No. 5 and the No. 2 strike faults have been described by Thomson (1950) as north dipping post-ore strike faults. These faults may be post-ore thrust faults similar to, and possibly a conjugate set with, the south dipping '04 North Break at the Macassa mine.

Related to the Kirkland Lake fault are a series of steeply dipping structures that are parallel, or branch off, the Kirkland Lake fault. These are weaker structures, but they may contain significant vein mineralization. The three most significant of these structures are the north-dipping North vein, the North A vein, and the North B vein (Narrows
Figure 2.7. North-south cross-section through the Sylvanite Mine looking east. Note the frequency of stopped ore in the upper portions of the mine in predominantly syenite porphyry. At the bottom levels of the mine there was far less ore, and most level development was in conglomerate with some extending into tuff (Charlewood, 1964).
break) (Figure 2.7). The three footwall structures were traced at depth to the No. 5 strike fault. Drilling beneath this structure did not reveal any ore-bearing structures or veins. The Lake Shore and Wright-Hargreaves mines to the west mined the continuation of the Kirkland Lake fault beneath the No. 5 fault. It is likely that the same structure continues mineralised beneath the No. 5 fault at Sylvanite.

In addition to these veins and structures are a series of less steep, south-dipping veins and fractures that branch off the steeper structures. The most significant of these veins are the Upper and Lower incline veins (Figure 2.7).

Most of the upper workings of the mine had ore hosted in syenite porphyry. At deeper levels, the southerly dip of the syenite porphyry stock means that more of the adjacent sediments are encountered (Figure 2.7). Most of the lower-level development has been in conglomerate, but it also extended into tuff units. Throughout the mine, veins have been mined in all of the rock formations with no apparent deviation in the nature of veins passing from one rock type to another except for localised mine offsets along the contacts.

Wright-Hargreaves

The Wright-Hargreaves mine is located to the east of Lake Shore in the central portion of the Kirkland Lake camp. It ranks second to Lake Shore in terms of gold production and grade, having produced 4 817 680 ounces of gold at a grade of 0.49 oz/t. The mine was developed down to the 8 100 foot (2 469 m) level, the deepest development in the Kirkland Lake camp. Diamond drilling below the 8 100 foot (2 469 m) level revealed several high-grade intersections persisting several hundred feet below the level. However, the cost to develop these intersections at such deep levels proved to be too high, and mining was not continued.

The Kirkland Lake fault is the most prominent structure crossing the Wright-Hargreaves property (Figure 2.8). This structure has been traced as a consistently strong fault down to the 8 100 foot (2 469 m) level, and by diamond drilling below this. A significant amount of ore was mined from this structure, however, most of the tonnage came from the North vein. The North vein branches off the Kirkland Lake Fault to the north just to the west of the property boundary with Lake Shore. Stoping on the North
Figure 2.8. Plan view of the structural geology of the Lake Shore and Wright Hargreaves mines from the 600 foot-level. Note the subvertical cross-faults that strike north to northeast. Extensive mining occurred on the North and South Veins on both properties. The Kirkland Lake Fault has been identified as the north structure to the west and into the Teck-Hughes property, while the southern structure has been identified as the Kirkland Lake Fault on Wright-Hargreaves property (from Thomson, 1950).
vein was extensive to about the 4 500 foot (1 372 m) level and development was to the 6
600 foot (2 012 m) level. Below this level, mining was concentrated along ore-bearing
fractures of the North vein zone, known as the North Heading Vein, North vein, and
North D Vein. These veins are typically dipping near 75° south.

Another significant mineralised structure is the South vein-fault which branches
off the south side of the Kirkland Lake fault in the western portion of the mine. As with
many of the other mines in the camp, there are also numerous veins that branch or splay
off the main structures and form along tension fractures in the wedge of ground between
major faults.

Post-ore faulting at Wright-Hargreaves has been well documented by the mine's
former chief geologist, Harold Hopkins (Thomson, 1950). The Lake Shore fault is the
most important post-ore fault in the western portions of the mine (Figure 2.8). This fault
strikes 012-025° and dips steeply to the east near surface, becomes vertical with depth,
then by the 5 000 foot (1 524 m) level dips to the west. This cross-fault has several
important faults branching off the east side including the F and L faults.

A series of four major, north-dipping "strike" faults have been numbered 1, 2, 6
and 5 (Figure 2.9). Nos. 1 and 2 faults generally dip at 45° or less to the north and
displace the Kirkland Lake fault and other vein zones some 150 and 300 feet (46 and 91
m) respectively with reverse movement (hangingwall displaced over the foot wall). The
No.6 strike fault has the smallest displacement averaging around 80 feet (24 m) (again
reverse movement), although it has a steeper dip of around 65°. The No.5 strike fault is
the most important of these faults and outcrops on surface as the Murdoch Creek fault. It
can be traced to the east across the Sylvanite and Toburn workings. The fault dips at
about 45° north on the Wright-Hargreaves property, but the dip appears to steepen with
depth. Displacement on this fault has a maximum of 700 feet (213 m)(reverse movement)
on the Wright-Hargreaves property.

Most of the ore mined at Wright-Hargreaves was found within syenite porphyry,
with veins north of the Kirkland Lake fault below the 6 600 foot (2 012 m) level mainly
in tuff, greywacke, conglomerate and granite porphyry located in the footwall of the main
syenite porphyry plug. The Kirkland Lake fault is located within syenite porphyry
throughout the mine. The north veins below the 6 600 foot (2 012 m) level are much less
Figure 2.9. North-south geological section through the Wright-Hargreaves Mine showing the nature of the numerous flat-dipping post-ore faults. Modified from Thomson, 1950. Subsequent sections by Charlewood (1964) showed deep level mining down to the 8100' Level on the North Vein.
continuous than veins in the upper levels hosted by syenite porphyry.

Lake Shore

The Lake Shore mine is located in the centre of the Kirkland Lake camp bounded to the west by the Teck-Hughes mine and to the east by the Wright-Hargreaves mine. Lake Shore may be thought of as the "crown jewel" of the Kirkland Lake camp, for it was by far the largest gold producer, producing 8,499,199 ounces at a grade of 0.51 oz/t from continuous production from 1918 until 1965. This is almost twice the total number of ounces produced from the neighbouring second highest producer, Wright-Hargreaves, and represents 36% of the total ounces produced from the entire camp (Table 2.2).

The mine was developed down to the 8,075 foot (2,461 m) level, where high-grade ore material was still being mined when the mine closed. Diamond drilling below this level indicates that the ore continues at depth and that the Kirkland Lake fault shows no signs of weakening at depth. Relatively low tonnage of ore at deeper levels and difficulties in mining at these extreme depths proved deepening of the mine workings to be uneconomical with the fixed gold prices of the day.

The Kirkland Lake fault and related sub-parallel structures strike continuously across the Lake Shore property but are offset by significant post-ore faulting along the Lake Shore fault at the east end of the property (Figure 2.8). Near surface, offset on this fault is 600-750 feet (180-230 m) horizontally and about 325 feet (99 m) vertically, with the east side down and north relative to the west side. The fault strikes about 012° and dips sub-vertically to the southeast. At deeper levels the fault appears as a strike fault and merges with the No. 5 fault between the 6,325 and 6,825 foot (1,928 and 2,080 m) levels. At the bottom levels of the mine, the strike of the fault follows the North vein.

The North, or No. 2 vein was the most productive structure at Lake Shore. This structure is continuous from surface down to the 8,075 foot (2,461 m) level and has been traced by diamond drilling for 800 feet (244 m) below this level. Between the 1,200 and 4,000 foot (366 and 1,219 m) levels, the Kirkland Lake fault branches into several faults. The North vein is the continuation of the Kirkland Lake fault at the west end of the property. At the east end of the property the Kirkland Lake break is represented by the South, or No. 1 vein which continues as the South vein on the Wright-Hargreaves
Mining on the North (No. 2) vein was extensive throughout the mine (Figure 2.10). Of these zones, the area containing mixed syenite porphyry and augite syenite west of the shaft area from surface to the 5450 foot (1661 m) level was most productive. Occasionally sub-parallel veins were mined separately from this vein, but in places the closely spaced veins have been stope together across width up to 70 feet (21 m). Stopping was nearly continuous on the North vein from surface to the 5400 foot (1646 m) level, where veining weakened considerably and stopped at the 6325 foot (1928 m) level. Another ore shoot continues below this from the 7575 foot (2309 m) level to the 8075 foot (2461 m) level the bottom level of the mine. This ore shoot was traced by diamond drilling down to 8500’ (2569 m) and showed no signs of weakening. The North vein on the 8075 foot (2461 m) level was mined over an 807’ (246 m) strike length at an average stopping width of 7.6’ (2.3 m) at an average grade of 0.677 oz/t.

The South (No. 1) vein was second in importance only to the North vein. This structure contains numerous branches, splays, and related veining, and it is far less continuous than the North vein (Figure 2.10). The ore also was not as extensive, with lower average stopping widths varying from 3 to 35 feet (1 to 11 m). Above the 1000 foot (305 m) level, the South vein is regular and is sub-parallel to the North vein which is some 400 to 500 feet (122 to 152 m) to the north. Below the 1000 foot (305 m) level, the South vein is much less regular and less continuous until finally the ore bottoms out on the 6075 foot (1852 m) level (Figure 2.10).

Several subsidiary veins have also been mined in the ground adjacent to these main structures. Most of these veins occurred between the North and South veins, where they formed along tensional fractures related to fault movements.

Another significant structure sub-parallel to the North vein occurs some 1200 to 1600 feet (366 to 488 m) to the north. It is referred to as the Narrows break or No. 3 vein zone and has been drilled and explored on various levels down to the 5450 foot (1661 m) level. While some high-grade intersections have been reported, no significant amounts of ore have been mined from this zone. This structure likely continues to the west and east and is called the ‘05 break at the Macassa mine (see later section).

Mining at Lake Shore was almost entirely within intrusive rocks, except in the
Figure 2.10. Longitudinal sections showing distribution of ore on the South (No. 1) vein and the North (No. 2) vein at the Lake Shore mine. Based on 1962 mine plans. (From Charlewood, 1964.)
upper levels of the mine to the 800 foot (244 m) level, where ore was found in conglomerate on the north side of the North (No.2) vein. Most of the ore is hosted in syenite porphyry, with augite syenite hosting some ore at the west end of the property. Syenite porphyry is the only rock type reported in the lower levels of the mine.

**Teck-Hughes**

The Teck-Hughes mine is bounded on the west by Kirkland Minerals, and by the Lake Shore mine to the east. The mine began production in 1917 and had produced 3,688,664 ounces of gold at a head grade of 0.38 oz/t when it ceased operating in 1968. The mine ranks third among the seven mines of Kirkland Lake in terms of total ounces produced, but had an average head grade considerably below the camp-wide average of 0.43 oz/t. This lower head grade was largely due to the fact that in the latter years of operation, the mine relied heavily on lower grade “slough ore” which had caved from the hangingwalls of open stopes.

As with other mines in Kirkland Lake, the most important structure at the Teck-Hughes mine is the Kirkland Lake fault. This structure and the veins related to it yielded most of the gold in the mine. The mineralised structure was mined as the No. 3 vein from surface to the 6,105 foot (1,861 m) level, the deepest level at the mine. Longitudinal sections reveal that stoping on the No. 3 vein was near continuous from surface to near the 3,000 foot (914 m) level. Diamond drilling defined the main break down to 6,650 feet (2,027 m), however there was insufficient ore to warrant development below the 6,105 foot (1,861 m) level. Grade and production both decreased below 3,000 feet (914 m). This decrease in ore with depth has been suggested to be directly related to a decrease in the proportion of augite syenite to syenite porphyry with depth (Charlewood, 1964).

The No. 4 break (not to be confused with the '04 break at Macassa) lies about 600 feet (183 m) south of the Main break and is generally believed to be the westerly extension of the South (No.1) vein of Lake Shore. Although this structure contains some low gold values, no ore has been mined along it in the Teck-Hughes mine. This fault may merge with the No. 6 break at depth and has never been identified in the western portions of the mine.

From 1938 onwards, veins in the hanging wall of the Kirkland Lake fault became
an important source of ore. These hanging wall veins are typical of other such veins in the Kirkland Lake camp which drape off the Kirkland Lake fault and dip flat to the south, generally between 30 and 50 degrees.

The relatively late discovery and subsequent mining of hanging wall veins can be attributed to a number of factors. Firstly, mining was concentrated on the Kirkland Lake break where stoping was extensive, and easily traced. Secondly, many of the initial diamond drill holes testing for ore associated with the Kirkland Lake fault were not extended any significant distance into the hangingwall. In later years, improvements in diamond drilling and reduced drilling costs, increasing realisation of the significance of the hangingwall veins, and the depletion of Main break ore led to more and more exploration holes probing the hangingwall of the Kirkland Lake fault revealing numerous significant ore-bearing veins.

**Kirkland Lake Gold**

The mine is near the western end of the Kirkland Lake camp bounded to the west by the Macassa mine and to the east by the Teck-Hughes mine (Figure 2.6). A total of 1 172 955 ounces of gold at an average grade of 0.37 oz/t was mined between 1919 and 1960. The mine ranks sixth out of the seven mines in Kirkland Lake in terms of total ounces produced and average head grade.

In the early years of the mine, most gold production came from workings on the Main Break Zone, until 1937, when significant production came from the No. 5 vein. The No. 5 vein was a 50° south dipping hangingwall vein structure which was mined as a continuous sheet of ore from the 3 475 foot (1 059 m) level to the 3 875 foot (1 181 m) level along a strike length of 1 200 feet (366 m). This vein rolls into the Kirkland Lake fault along a line plunging to the west at 17°. The vein is subparallel and in the hangingwall of the No. 6 break (Figure 2.11).

Another major source of ore from the mine came from a series of veins that were mined from the 3750 foot (1 143 m) level to the bottom 5 975 foot (1 821 m) level between the main break and the No. 6 fault. The No. 6 fault (as shown in Figure 2.11) branches from the Kirkland Lake fault below the 3 375 foot (1 029 m) level at the eastern boundary of the mine dipping 40-60° south and plunges to the west near 20° along the
Figure 2.11. North-south section through Kirkland Minerals (Kirkland Lake Gold Mine) showing the Kirkland Lake Fault (Main Break), the No. 6 Break, and the No. 5 vein (from Thomson, 1948).
line of intersection with the Kirkland Lake fault (this structure is described in more detail in the following chapters, where it is encountered on the Macassa property). The veins associated with this structure formed a zone up to 250 feet (76 m) wide and up to 1 500 feet (457 m) along strike, that was nearly vertical and plunged gently to the west. Locally, up to seven sub-parallel veins were mined "across the width of the zone" (Charlewood, 1964).

Another source of ore was from a series of veins related to an anticlinal structure between the 3 750 foot (1 143 m) level to below the 5 725 foot (1 745 m) level, where it plunged west into Macassa. The No. 10 vein was the most prolific of these veins being mined from the 5 230 foot (1 594 m) level to below the 5 600 foot (1 707 m) level. The axis of the folded vein strikes near 125° and plunges to the west near 30°. Various veins have been mined on both the south and north limbs of the anticline with one vein mined around the nose of the anticline. The veins are steeper on the limbs and flatter towards the top of the anticline. None of the veins have been reported to intersect the Main Break.

**Macassa**

A more detailed and comprehensive description of the Macassa Mine follows in Chapter 3.
Chapter Three  
Macassa Mine Geology  

Introduction  

The Macassa gold mine was in continuous production from 1933 until operations were suspended indefinitely in June 1999. Presently owned by Kinross Gold Corporation, the mine has a long and rich history (Kinross, 1996; summarised below). The original mine was developed on 11 key mining claims by Macassa Mines Ltd that organised in 1926 and obtained the assets of United Kirkland Gold Mines Ltd in 1933. In 1962 the company combined with Bicroft Uranium Mines Ltd and Renabie Mines Ltd to become Macassa Gold Mines Ltd. Amalgamation in November 1970 with Willroy Mines Ltd and Willecho Mines Ltd created the parent company Little Long Lac Gold Mines, located in Toronto. Upper Canada Mine Ltd optioned management rights from 1970-1976. In December 1982, the amalgamation of several groups, including Little Long Lac Gold Mines, created Lac Minerals Ltd (Macassa Division). In August 1994, Barrick Gold Corporation successfully took over Lac Minerals Ltd and Kinross Gold Corporation bought the Kirkland Lake Operations from Barrick in May 1995.  

The first shaft was the 500-foot (152 m) Elliot shaft (Figure 2.6) which was developed on the Main Break Zone in the late 1920’s. Mining was unsuccessful and operations halted. In 1931, development westward onto Macassa ground from the 2475 foot (754 m) level of the Kirkland Lake Gold Mine discovered ore on the Main Break for 700 feet (213 m) along strike and in subsidiary hangingwall veins. These underground workings were connected with the 3100 foot (945 m) No.1 shaft, and later by 2 winzes to greater depths. The No.1 winze connected the 3000 to 4625 foot (914 to 1410 m) levels and the No. 2 winze the 4625 to 6875 foot (1410 to 2096 m) levels. The No. 2 shaft was sunk from surface to a depth of 4625 feet (1410 m) about 1000 (305 m) feet southwest of the No. 2 shaft. In 1986, the No. 3 shaft was sunk from surface to the 7050 foot (2149 m) level, to a final depth of 7225 feet (2202 m). Until the mid-1990’s this was the deepest single lift-shaft in the Western Hemisphere. The No. 3 shaft gave access to 21 levels from 3800 feet (1158 m) to the 7050 foot (2149 m) level until 1997. As a result of
a rockburst on April 12, 1997, only the levels from the 4250 foot (1295 m) to 5000 foot (1524 m) levels were reactivated for mining. Exploration development was underway on the 3800 foot (1158 m) level, when production was halted in 1999. The shaft was temporarily capped in August 2000 to eliminate the high costs of underground pumping.

Since active production began in 1933, until the end of 1988, more than 115 kilometres of underground drifting and cross-cutting has occurred on 51 levels/sub-levels (Kinross, 1996), and from the date of initial production until the end of 1997, well in excess of 500 km of core were drilled.

The first mill began operation in October 1933 at a capacity of 200 tons per day. The milling rate was increased to 425 tons/day in 1949 and to 500-525 tons/day in 1956. In August 1988, a new mill was built which could process 500-600 tons of rock and 750 tons of tailings per day. By 1996, modifications had increased capacity to 900 tons of rock per day and 1000 tons of tailings per day. At the time of closure in 1999, mill capacity was near 1600 tons of rock per day, or 600 tons of rock and 1400 tons of tailings per day.

Production statistics for the Macassa Mine from 1933-1999 are listed in Table 3.1 and illustrated in Figure 3.1. These statistics show that during 1998, the 3.5 millionth ounce was produced.

**Description of Host Rocks**

The rocks at the Macassa mine have been described in detail in previous works on the mine itself and in reports dealing with the geology of the Kirkland Lake Camp (Todd, 1928; Thomson, 1950; Charlewood, 1968; Watson, 1984; Lackey, 1990). A brief overview of the significant rock types within the mine is presented here.

The Macassa mine and surrounding area is underlain by sedimentary and volcanic rocks of the Archean Timiskaming Group. These rocks are several kilometres thick, and trend to the east. They flank and are nearly parallel to the strike of the Kirkland Lake-Larder Lake Break and unconformably overlie pre-Timiskaming volcanic rocks belonging to the “Abitibi Supergroup” which include the Blake River Group volcanics and the predominantly tholeiitic Kinojevis Group (Jensen and Langford, 1983). Although
Table 3.1. Macassa Mine production statistics, 1933-1999 (grades in oz/t).
Macassa Milling Statistics 1933-1999

Figure 3.1. Milling statistics for the Macassa Mine, 1933-1999.
these pre-Timiskaming volcanics are ubiquitous in the surrounding district. They have not been encountered in any of the Macassa mine workings.

Intruded into the Timiskaming sedimentary and volcanic rocks is a composite syenitic stock that is broadly centred on the town of Kirkland Lake. The long axis of the stock is roughly parallel to the strike of the Timiskaming rocks, and the body dips steeply to the south. The three main components of the syenitic stock and related dykes are augite syenite, felsic syenite, and syenite porphyry. These intrusive rocks host most of the ore at the Macassa mine.

The youngest rocks at Macassa are a series of diabase dykes which post-date mineralization and are frequently associated with late cross-faults.

A. Timiskaming Group

i) Conglomerate. Conglomerate-hosted ore makes up a minor component of the total ore produced at the Macassa mine. Most of the conglomerate encountered in the mine is in development to the north or south of the '04 and Main break planes or in exploration diamond drill holes to the north or south of this plane (Figure 3.2).

The conglomerates found in the Macassa mine are classical Timiskaming-type conglomerates with characteristic red jasper pebbles (Mueller et al., 1992; 1994). They most commonly consist of a fine-grained sandy or silty matrix that supports rounded to sub-rounded pebbles generally ranging in size from 2 cm to 10 cm in diameter. Although red jasper pebbles are characteristic, they form a minor overall component of the pebbles usually making up less than 2% of the total. The clast populations in the conglomerates are extremely diverse with the main clast components being porphyry (mostly quartz monzodiorite with minor spessartite lamprophyre), trachyte (trachytic volcanic and volcaniclastic rocks), tholeiitic basalt (with minor andesite and komatiitic volcanic rocks), sedimentary rock (chert and epiclastic sedimentary rock), tonalite (holocrystalline tonalite and trondhjemite), and other minor components (Legault and Hattori, 1994).

ii) Greywacke. Greywacke is the mine term used for lenses of medium to fine-grained massive sedimentary rocks commonly dispersed as lenses throughout conglomerate units in the mine. These light to dark grey sandstone to mudstone units
Figure 3.2. Level plan of the 6050' Level in the Macassa Mine. All major structures are shown as are rock types visible at this scale.
have well-preserved graded bedding. They occur along both the northern and southern flanks of the intrusive rocks. Petrographic studies reveal a composition of angular quartz and feldspar fragments in a matrix of quartz, chlorite, biotite, feldspar, and lesser amounts of carbonate materials (Watson, 1984).

iii) Tuffs. Volcanic tuffs are far more common at Macassa than conglomerate and greywacke combined. The tuffs consist of a diverse range of pyroclastic flows and reworked waterlain tuffs. They have been studied in great detail by a number of authors, especially Lackey (1990) who meticulously described the various tuff units and separated them into fourteen stratigraphic units.

Most of the tuffs at Macassa consist of fine-grained to sandy cherty tuffs with well preserved primary bedding and depositional features including normal and reverse grading, cross-bedding, parallel laminae and scour channels (Lackey, 1990). Also common are a series of coarser units consisting of lapilli tuffs and agglomerates. These units may contain blocks and bombs of leucitic lava and pumice that are commonly several centimetres, but may reach more than 10 cm in diameter.

iv) Trachyte. Trachyte is not commonly observed underground at Macassa, but it is a very distinctive volcanic unit that is worthy of mention. Trachyte consists of a fine-grained, light grey to light brown matrix with distinctive pseudoleucites (altered to chlorite and sericite generally 1-2 cm in diameter which give the rock its classic “spotted” nature (Lackey, 1990)). Trachyte is most commonly found intercalated with extensive tuff units.

B. Intrusive Rocks

i) Augite (Basic) Syenite: The composite syenitic stock, which is centred near the town of Kirkland Lake and the Lake Shore mine, extends to the west into the Macassa mine workings. The syenite at Macassa is predominantly augite-rich (basic syenite) with lesser amounts of felsic syenite and syenite porphyry (Figure 3.2). The main body of the stock outcrops on surface at the Sylvanite, Wright-Hargreaves, Lake Shore, and Teck-Hughes mines but plunges to the west beginning at the Kirkland Minerals property so that at the No. 3 shaft on the Macassa property the top of the syenite stock is close to 4000'
(1 219 m) below surface. This plunge is similar to the plunge of the mined areas of the camp as shown in Figure 2.6.

The augite syenite at Macassa is a common host rock for gold mineralization along the '04 Break and other related structures (figure 3.2). The fresh rock is dark grey-green with a coarse-grained equigranular texture consisting primarily of augite and alkali feldspars. The augites are well formed euhedral tabular laths to 5 mm in length, which show a distinctive light green alteration colour. Numerous "felsic ribs" within the syenite are generally less then 6 inches (15 cm) in width and are characterised by a distinctive orange-brown colour. They are thought to represent a fractionation of felsic syenite within the basic syenite mass. Detailed descriptions of basic syenite including petrochemical data may be found in Todd (1928), Thomson (1950), and Watson (1984).

i) Felsic Syenite: For descriptive purposes, a syenite with <25% mafic minerals is termed felsic syenite at Macassa. Felsic syenite is less common throughout the Macassa mine but still hosts a significant proportion of ore material. Felsic syenite is more abundant in the upper levels of the mine, particularly in the east end, than in the lower levels. It is similar in texture and composition to the augite syenite but has less mafic minerals. The felsic syenite has a lighter appearance, often having a brown-orange colour. Detailed descriptions and the chemical composition of felsic syenite can be found in Todd (1928), Thomson (1950), and Watson (1984).

ii) Syenite Porphyry. Porphyritic feldspar syenites constitute a major portion of the intrusive rocks at Macassa. Syenite porphyry occurs intermingled with felsic and augite syenite but is not the predominant igneous host rock as in the central portion of the Kirkland Lake camp at the Lake Shore, Wright-Hargreaves, and Sylvanite mines which are centred on a largely feldspar porphyritic syenite stock. The porphyritic syenite intrudes both augite and felsic syenite as minor dykes and as small sills with sharp contacts that may exhibit chilled margins. The syenite porphyry is the latest phase of the intrusive units.

The syenite porphyry is generally red-brown to grey-brown and has distinctive feldspar phenocrysts averaging 3-5 mm in diameter. Watson (1984) has shown that these phenocrysts are dominantly plagioclase (Ab\textsubscript{10} -Ab\textsubscript{95}). At various locations the phenocrysts
are bimodal when a second set of plagioclase phenocrysts that average near 10 mm in diameter is present. This unit is referred to as bimodal porphyry throughout the mine.

Another distinguishing feature of syenite porphyry is the presence of irregular-shaped xenoliths of mafic rock that may comprise <2% of the total rock. They range from 2 mm to 20 cm in diameter but generally average near 3-5 cm in diameter. The source of these xenoliths may be the ubiquitous pre-Timiskaming Group volcanic rocks (Watson, 1984). Detailed descriptions of the porphyritic syenites can be found in Todd (1928), Thomson (1950), and Watson (1984).

C. Late-Stage Dykes

A series of late-stage sub-vertical diabase and minette dykes cross-cut all rock types throughout the Macassa mine. The minette dykes are micaceous lamprophyres, and have localised occurrences with widths less than 1-2 m. The diabase dykes can be continuous along strike and down-dip for several kilometres at widths that may exceed 5 m. The diabase dykes are associated with the Matatchewan dyke swarm. Dykes have been reported at various locations, including approximately 325 m west of the No. 1 shaft and near the No. 2 winze on the lower levels (Watson, 1984). Diabase dykes are also associated with late cross-cutting faults such as the Amikougami Creek cross fault.

Alteration

Alteration of the wallrock adjacent to mineralised zones in the Kirkland Lake camp has occurred through mechanical deformation of original textures and through chemical and mineralogical changes related to hydrothermal alteration (Thomson, 1950; Watson, 1984). Alteration is strongest and most noticeable adjacent to fault-related ore zones in intrusive bodies. Alteration adjacent to hangingwall veins or footwall veins is much less extensive, and the rocks lack deformation fabrics. These veins are believed to have formed along extensional fractures (Thomson, 1950). The altered zones do not contain sufficient gold to make ore without the presence of quartz or silicification.

Wallrock adjacent to fault-related mineralization is commonly strongly deformed, brecciated, or foliated and reddened, bleached and or silicified for several feet on either
side of the main fault. These alteration effects can be observed on a microscopic scale as well as a broad scale in development through altered areas (more detailed discussions of alteration is discussed relative to the major structures in the proceeding chapter). Zones of alteration are rich in chlorite, sericite, and leucoxene, and they show secondary enrichment in quartz and pyrite (Watson, 1984). Carbonatisation is pervasive in altered areas and wide zones of carbonisation for up to widths of 325 feet (100 m) have been reported in the system of hangingwall veins at Macassa (Thomson, 1950).

Alteration in sediments and tuffs is represented by discrete colour changes to red, brown, or green. This is caused by the coating of multiple microfractures with fine disseminated particles of red hematite, brown limonite or goethite and ferriferous carbonate and sericite (Thomson, 1950).

Detailed geochemical work at the Macassa mine by Watson (1984) showed that the wallrocks adjacent to gold ore is enriched in SiO₂, S, and K₂O and depleted in Na₂O. Carbonate gangue minerals in these areas formed through the alteration of Fe-, Mg-, Ca-, Mn- silicates to Fe-, Mg-, Ca-, Mn-carbonate minerals by CO₂-bearing hydrothermal solutions. Pyrite in the altered wallrock formed in a similar way as hydrothermal fluids rich in sulphur broke down iron-bearing silicates.

**Mineralization**

Gold mineralization at Macassa has been discussed in great detail in previous reports (Kerrich and Watson, 1984; Thomson, 1950; Charlewood, 1964; and Ball, 1984). Listed below is a brief summary by Watson (1984). Detailed descriptions and analysis of the various ore types and related structures are presented in Chapter Four.

Three major types of gold ore are found at Macassa: break-related ore, hangingwall and footwall veins, and breccia ore (Watson, 1984).

Break ore occurs continuously along major faults (breaks), and related branches at Macassa. These major faults (breaks) all typically trend near 060° and dip steeply to the south from 70 to 80° (see Figure 3.3). The '04 break is the most significant of the ore-associated faults at Macassa and was mined from section 16E west to the Amikougamí Creek fault (near 50W) and from the 4250' (1295 m) level to the 7050' (2150 m) level.
Figure 3.3. Plan of part of the 4750' Level illustrating break relationships and associated veining (modified from Kinross files). Note how the '04 break is connected to the Main break via the S break and the Main break -North Branch (R-2) at the east end of the level.
Further to the east, significant mining was conducted on the Main break. Significant mining was also conducted along the R-2 break and the South break.

Break ore typically occurs as mineralised zones of fractured and brecciated quartz within the fault gouge or in the immediate hangingwall or footwall of the fault as fragmental quartz zones or as discrete veins. The quartz zones are typically 1' to 5' (0.3 to 1.5 m) wide, with gold occurring in fine, native form along with lesser amounts of tellurides (chiefly altaite). Overall sulphide content is near 1-3%, with the vast majority of this occurring as pyrite. Fine native gold may occur in chlorite fault gouge, however, this is generally in minor amounts and rarely will make ore without the presence of quartz.

Vein ore at Macassa occurs primarily as hangingwall veins to the major faults or breaks. Footwall veins are also present but are far less common and make up a much smaller portion of ore than hangingwall veins. Hangingwall and footwall veins typically occur as quartz-filled fracture zones from 1” to 2” (2.5 cm to 60 cm) wide. They dip from sub-vertical to sub-horizontal, and are most common in close proximity (within 30 m) to major faults. They occur as single veins to multiple sheeted or stacked vein systems adjacent to major faults. Generally, most veins are defined by a sharp chlorite +molybdenum coated slip or fault and show evidence of repeated episodes of mineralization. Gold typically occurs in its native form in fractured vein quartz along with tellurides, predominantly altaite and calaverite. Total sulphide content is usually 1-3%, comprised chiefly of pyrite.

Breccia ore is characterised by mineralised lensoidal and fragmental quartz in wide zones (generally up to 15 m) confined by a major fault in the hangingwall and footwall. Between the two faults, the host rock is altered, silicified and strongly fractured, generally with 1-4% total sulphides. The sulphides occur mainly as pyrite with the mineralised quartz containing native gold and tellurides. Outside the hangingwall and footwall contacts, the host rock is distinctively less altered and fractured and is not mineralised.

Four major zones of breccia ore are present at Macassa: 1) between the ’04 break (north contact) and South break (south contact) between sections 28W to 34W between the 5025’ and 5400’ (1 532 and 1 646 m) levels; 2) between the footwall fault / North
break (north contact) and '04 break (south contact) between sections 21W and 25W between the 5700' and 6300' (1 737 and 1 920 m) levels; 3) between sections 33W to 38W between the 6100' and 6400' (1 859 and 1 951 m) levels; 4) south of the '04 break between sections 17W to 21W between the 4750' and 5450' (1 448 and 1 661 m) levels.

A number of different authors have studied in detail the ore mineralogy at Kirkland Lake: Burrows and Hopkins (1923), Todd (1928), Wark (1948), Hawley (1950), and McInnes (1985). This work has demonstrated that there are a number of different telluride minerals occurring with native gold in mineralised quartz zones. These various minerals are listed in Table 3.2. The most common of the telluride minerals is altaite (PbTe) which occurs with native gold in high-grade portions of veins. Other common tellurides include calaverite (AuTe2), petzite (AuAg3Te2), hessite (AgTe), melonite (NiTe2), and coloradoite (HgTe).

The pyrite content of veins is not directly related to gold content. Veins can be pyrite-rich and contain little or no gold, but rarely does a vein contain high levels of gold and little or no sulphide minerals. High-grade veins are also characterised by high concentrations of molybdenum and graphite, which can be seen in hand, samples and in thin sections as thin coatings on fracture surfaces. Todd (1928) reported that the ratio of native gold to gold in tellurides is 8.4 : 1.6 and that approximately 5.5% of silver occurred amalgamated with native gold.
## MINERALOGY OF THE KIRKLAND LAKE ORES

### METALLICS

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### NON-METALLICS

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Table 3.2. Mineralogy of the Kirkland Lake ores, from Hawley (1950).
Chapter Four
Structural Geology of Macassa

Introduction

The Macassa mine is a structurally controlled gold deposit. Structures controlled intrusion of the syenitic stocks, emplacement of the mineralising hydrothermal fluids, and post-ore displacement along the breaks and cross-faults. Previous reports by Todd (1928), Thomson et al., (1950), Charlewood (1969), Watson (1984), and Lackey (1990) have discussed the major structures of the Kirkland Lake camp including those occurring in the Macassa mine. This chapter will review the major structures at Macassa. Information from recent mining is added, as there has not been a comprehensive review of the structural geology of Kirkland Lake gold camp since Charlewood (1964) updated the deep level developments of the camp.

There will also be discussions on recently discovered and / or mined zones within the Macassa mine that are related to structures significant on a mine-wide scale. Many of these zones will be discussed in a context that allows them to be compared to the same or similar structures within other mines of Kirkland Lake. These comparisons will be further discussed in proceeding chapters relating to exploration.

Major Mineralised Structures

‘04 Break

Introduction

The ‘04 break is the most important structure in the most recently worked areas of the Macassa mine. It is sub-parallel to the Kirkland Lake Fault (Main break), strikes near 060°, dips 70°-80° south, and is connected to the north branch of the Main break at the east end of Macassa via the S and R breaks (Figure 3.3). The ‘04 break continues as a strong fault structure east of this area of transfer faults between the two major break structures, but lacks major zones of alteration and is not known to be ore-bearing. The Main break continues to the east as the stronger of the two structures and is the most important ore-related structure in the Kirkland Lake camp (see previous discussions in
All of the studies dealing with offset along the '04 or Main break structures have recognized an overall net thrust displacement that is rotational and greatest to the west (Table 4.1). The main disagreement between authors has been whether the net thrust offset along the breaks was pre-ore (i.e. Thomson et al., 1950; Charlewood, 1964; McGregor, 1996; Watson, 1984) or post-ore (Kinross, 1996; Lackey, 1990). Based on observations presented in this thesis, the author believes that a major period of reverse faulting post-dated the major period of mineralization.

The '04 break strikes sub-parallel to the strike of the sedimentary units and the long axes of the syenitic intrusions, and the break transects all major rock types in the mine. The '04 break has been developed for mining and is accessible for approximately 4400' (1 341 m) of strike length on most recently active mine levels from the 4250' (1 295 m) to 5025' (1 532 m) levels. This strike length is continuous from the east at the intersection with the S break (6W section) to the west at the intersection with the Amikouamai Creek fault (50W section) (Figure 3.3). Development west of the Amikouamai Creek fault on the 4750' (1 448 m), 5875' (1 791 m), 6450' (1 966 m), and 7050' (2 149 m) levels, on a structure believed to be the '04 break, failed to encounter any significant ore-grade material. Limited exploration was completed in the 1980's and early 1990's on the '04 break on the 3800' (1 158 m) level near section 41W to the north of the #3 shaft. Exploration drilling supervised by the author in late 1997, targeting the '04 break near the 3800' (1 158 m) elevation, drilled from the 4250' (1 295 m) level, encountered encouraging results. This prompted a $2.1 million exploration project for 1998-1999 which included over 1000' (305 m) of drifting on the '04 break to the east towards the Tegren fault. A major diamond drilling program from drill stations on the newly developed 3800' (1 158 m) level in 1999 defined ore related to the '04 break on the 3800' (1 158 m) level and above. Further exploration and development on the '04 break, from the 3800' (1 158 m) level, was halted in June 1999 when underground operations at the Macassa mine were suspended.

Development occurred on the '04 break on all levels at Macassa from the 4250' (1 295 m) level to the 7050' (2 149 m) level. Diamond drilling beneath the 7050' (2 149 m)
<table>
<thead>
<tr>
<th>Calculated Displacement</th>
<th>Notes</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,020' and 1,100' (311 and 335 m) (Reverse movement)</td>
<td>Vertical sections at the Kirkland Lake Gold Mine through the Main break. Used a contact between lamprophyre (sill) and greywacke. Greywacke and conglomerate horizon contact.</td>
<td>Tyrrell and Hore (1926)</td>
</tr>
<tr>
<td>1,850' and 1,875' (564 and 572 m) (Reverse movement)</td>
<td>South-dipping North Vein portion of the Kirkland Lake break at Kirkland Lake Gold Mine. Used a tuff - conglomerate contact.</td>
<td>Todd (1928)</td>
</tr>
<tr>
<td>Rotational Displacement</td>
<td>The first to recognise a rotational component of displacement. The Pivot Point was calculated to be near the west boundary of the Wright-Hargreaves Mine at about the 2,600' level. A counter-clockwise rotation of about 17° produced a fairly accurate match between footwall and hangingwall geology.</td>
<td>Hopkins (1940)</td>
</tr>
<tr>
<td>1,500' (457 m) at west end of camp, 350' (107 m) at east (Reverse rotational)</td>
<td>Outline of a pitching pipe-like body of felsic syenite completely below surface.</td>
<td>Thomson (1950)</td>
</tr>
<tr>
<td>16° rotational counterclockwise displacement</td>
<td>Used a north-westerly pitching syenite pipe offset along the '04 break at Macassa. Calculated a net reverse displacement of 1,360' (415 m) at section 20W.</td>
<td>Wright (1979)</td>
</tr>
<tr>
<td>4,020' (1,225 m) (Reverse movement)</td>
<td>Used the MVBU (middle volcanic breccia unit) of the Goodfish Tuff Formation offset by the Kirkland Lake break.</td>
<td>Lackey (1990)</td>
</tr>
</tbody>
</table>

Table 4.1. Calculated displacements along the major faults of Kirkland Lake.
level revealed mineralised portions of the '04 break continuing for at least another 500' (152 m) below the level, with the break continuing to greater depth. The '04 break is not consistently identified in the upper and lower portions of the mine (Figure 4.1). Above the 5725' (1745 m) level, two major structures are identified respectively from south to north as the South break and the '04 break. Below the 5725' (1745 m) level, the same apparent two structures are identified from south to north as the '04 break and the North break (see subsequent sections on the North and South breaks). This apparent confusion in nomenclature of these structures coincides with the former division of the mine into Upper and Lower beats between the 5700' and 5825' (1737 and 1775 m) levels.

At exposures underground, the '04 break typically occurs as a 1-2" (2.5 to 5 cm) mud gouge fault in a zone of intense deformation and alteration several feet wide. The coherent fabric of the overall break zone typically consists of brecciated and strongly bleached and altered wallrock fragments, fine-grained mylonite, and a series of sub-parallel braided and inter-connected chlorite slips and faults. Figure 4.2 shows the typical nature of the '04 break from an underground exposure on the 4750' (1448 m) level. Alteration and mineralization are usually most intense on the hangingwall side of the fault above the 5725' (1745 m) level and in the footwall side of the fault below this level.

The nature of the break can be quite variable, which causes difficulty in identifying the '04 break in areas where there are several faults. At some locations, the '04 break appears as no more than a ½" (1 cm) chlorite fault, at others it can be a 1-3" (2-8 cm) chloritised mylonitic structure, and at other places the break can be a 6" (15 cm) wide mud-gouge fault. The '04 break is not always the strongest structure in an area of branching or splaying faults.

**Mineralization**

Mineralization associated with the '04 break consists of quartz veining and quartz flooding and brecciation containing pyrite, native gold, and tellurides (see Thomson et al., 1950 for mineralogical descriptions of the Kirkland Lake ores). Ore zones are generally in quartz veins up to several feet wide. Localised zones with multiple quartz veins and silica-flooding may have widths in excess of twenty feet. Quartz veins are
Figure 4.1. Cross-section looking east along section 31+50 through the Macassa Mine. Note the apparent misidentification of the ‘04 Break below -5600 El.
Figure 4.2. East face of the 4729.32 Sub. #2. The figure shows a close-up of the '04 break zone in strongly altered and deformed basic syenite. At this location, the '04 break appears as a 2-5 cm wide, strongly brecciated, chlorite-healed, mud fault with strong mylonitic deformation evident in the footwall of the fault (left side of image). Gold mineralization occurs in dark quartz located in the hangingwall of the break at this location. The red paint line was painted by the beat geologist as a guide for the underground crew to advance the face holding the '04 break as the footwall (left) contact. Pencil for scale.
typically sub-parallel to the orientation of the break, but may also "roll off" the break at flatter angles, or may be steep to sub-vertical north dipping (see Figures 4.3 and 4.4). This type of ore is referred to as "break ore". Such ore has been mined extensively along the '04 break and the Main break, and was the most important source of ore for the Kirkland Lake camp.

Break-related ore is found in the hangingwall of the '04 break in the upper levels of the mine above the 5725' (1 745 m) level. Between the 5725' (1 745 m) level and about 6000' (1 829 m) depth ore is found in both the footwall and hangingwall, and below about 6000' (1 829 m), break ore is located in the footwall of the break.

In addition to break ore, there is also breccia ore. Breccia ore is characterised by extremely wide zones of quartz fragments, stringers, and veins in zones confined by two break structures. The '04 break forms either the footwall or hangingwall contact in such breccia zones (Figure 4.5).

Mineralization may occur in all rock types, but augite syenite is the most common host at Macassa. Syenite porphyry and felsic syenite may also be well mineralized, but are a less common host rock. Tuff is a common rock type adjacent to the '04 break, but is not a major host of ore. Conglomerate is seldom encountered along the '04 break and hosts no significant mineralization at Macassa.

Mineralization usually occurs in high-grade shoots or plunges with strike lengths of several hundred feet (~100 m). These ore shoots will generally plunge to the west at dips similar to or slightly steeper to the overall camp plunge (Figure 2.5). Although a continuous structure through the mine, not all stretches of the '04 break are ore-bearing. Only zones with quartz veining and flooding have the potential to make ore.

Historically, diamond drilling has a near 25% chance of hitting ore on '04 break related zones. There are several key characteristics of auriferous zones that serve as a guide for locating areas with the best potential to make ore.

1) **High-grade shoots or plunges.** High-grade shoots or plunges can extend for over a thousand feet up or down dip and for several hundred feet along strike.

2) **Structurally complex areas.** Areas of the '04 break, where multiple generations or sets of sub-parallel faults or breaks are present, are the most
Figure 4.3. Composite image of the 7038.50 PUC, facing east. Since this stope was an underhand paste cut and fill stope, paste is evident along the backs. The '04 break is along the south wall (right side) with quartz veining and mineralization footwall to the break. The mineralised zone consists of a fragmental quartz flooded zone immediately footwall to the break, a massive 2.8' (0.85 m) wide quartz vein, and a 43° south-dipping quartz vein on the north (left) side of the face. The entire face is hosted by basic syenite. Samples taken by the author across the face yielded 1.68 oz/t over 11.6' (3.5 m) (internal cut at 3.50 oz/t).
Figure 4.4. View of the 7038.50 PUC stope, facing west. This face shows quartz veining in the hangingwall of the '04 break in basic syenite. The main quartz vein on the left is steeply south dipping. Numerous smaller north dipping quartz veins can also be seen at the right hand side of the photo. Both sets of quartz veins make ore across the face. 2" (5 cm) hose on jack-leg for scale.
Figure 4.5. Plan view of the 6733 area (6750' level, section 33W) showing a wide zone of breccia ore footwall to the '04 Break. In this area the wide ore is confined to the north by the Footwall Fault. Further to the north is the North Break. The Tegren Fault intersects the '04 Break near the right hand side of the sketch, truncating the '04 Break and the ore.
likely to be mineralised. Locations where the '04 break changes dip or strike are also likely locations for ore to be present.

3) *Host rocks.* Basic syenite is the most common host rock for break ore at Macassa. Outside of the central zone of syenitic intrusives, there is far less mineralization.

**Timing and Nature of Deformation**

Following mineralization, deformation related to the Kenoran orogeny (2 710 Ma to 2 660 Ma ago, Card and Poulsen (1998)) caused reactivation of pre-existing major faults, including the '04 break, as reverse or thrust faults. Post-ore faulting along major structures can be recognised along sections of the '04 break (Figure 4.6). Late faulting and mylonite development overprint existing mineralised zones in this example (Fig. 4.6).

A series of intermineral felsic green dykes also overprint mineralised quartz veins associated with major structures including the '04 break. Intermineral dykes cut strongly mineralised gold-rich quartz veins, but the dykes themselves may be locally mineralised. However, it is not always clear if the dyke is mineralised or if fragments of pre-existing gold-rich veins occur within the dyke. Where mineralised, the dykes appear strongly silicified with ubiquitous sulphides comprising up to 5% of the total rock. An excellent example of such a dyke is found in ore-grade quartz veins in the hangingwall of the '04 break in the 4729 area (Figure 4.7). A grab sample of the silicified felsic dyke at this location assayed 0.52 oz/t Au.

The dykes themselves are poorly understood in terms of composition and absolute age. However, they should be accurately dated to establish a timing constraint for the gold mineralization.

**Main Break**

The Kirkland Lake fault, or Main break, extends across the properties of the seven past-producing mines of the Kirkland Lake camp (Figure 2.4). Most of the over 24 million ounces of gold produced in the camp were mined from mineralization in close proximity and/or directly related to this structure. Most of the mining activity in recent
Figure 4.6. Photomicrograph of the '04 Break from the 4711 area. The '04 break appears as a distinct fault at the top of the figure. The '04 break has been reactivated and overprints the earlier penetrative deformation and mineralization. Zone of mineralization at the bottom of the image is hangingwall to the break in space.
Figure 4.7. 4729.32 Sub No. 2. Intermineral dyke injected between a massive quartz vein located in the hangingwall of the '04 break. The dyke contains 3-4% sulphides and is strongly silicified with some minor quartz fragments. The dyke clearly post-dates the strongly mineralised multi-ounce quartz vein. A grab sample from the dyke returned an assay of 0.54 oz/t. This may indicate that the dyke is mineralised, or that the dyke was contaminated with mineralised quartz fragments during its emplacement.
years at Macassa has come from ore associated with the '04 break. This structure is connected to the North branch of the Main break at the east end of Macassa via the S and R breaks (Figure 3.3).

Previous reports have gone into great detail describing the Main break (i.e. Todd, 1928; Thomson et al., 1950; Charlewood, 1964; and Lackey, 1990). It dips on average 75° to 80° south, and strikes near 067°. The strike of the Main break is sub-parallel to the trend of the Timiskaming sedimentary units, and the long axes of the syenitic intrusives. In the central and eastern portion of the camp, the break branches into an increasing number of splays with displacement on the splays decreasing as their numbers increase. In the western portion of the camp the break is mainly a single fault plane with zones of sub-parallel splays and branches. Portions of Chapter Two of this thesis provided details of the Main break in the central and eastern portions of the camp.

Wright (1979) summarised the nature of the Main break at Macassa. The Main break has an average dip of 80°S above the 3500' (1 067 m) horizon, and flattens to nearly 50°S down to the 4125' (1 257 m) horizon in the eastern and central locations of the mine. The break splits into a North and South branch below the 4125' (1 257 m) level west of the No.1 winze (Figure 4.8).

The South branch dips approximately 50°S and diverges from the North branch by about 20° moving to the west in plan view. In cross-section, this branch also diverges from the North branch due to its flatter dip and crosses out of the mine workings near the 4900' level at the eastern end of the mine (Figure 4.8). The South branch is not known to be ore-bearing below the 4375' (1 334 m) level.

The North branch of the Main break dips 70° to 80°S and is the main ore source in the western portion of the mine below the 4375' (1 334 m) level. There is a plunge to the east of the intersection of the North and South branches below the 4625' (1 410 m) level in the central portion of the Macassa property. The North branch reverses dip to the north at the eastern margins of the property beneath the 4900' (1 494 m) level (Figure 4.8).

The '04 break is located some 400 feet (122 m) to the north of the North branch of the Main break and is connected to the North branch via a series of cross-over faults including the S and R breaks (Figure 3.3). Towards the west, these faults appear to have
Figure 4.8. Cross-section facing east through the Macassa Mine showing the '04 break and Main break. Note the zone of north-dipping mineralised structures connecting the two structures (from Charlewood, 1964).
transferred the regional stresses from the plane of the Main break onto the plane of the '04 break.

The Main break and the '04 break have similar magnitudes of net reverse displacement (Table 4.1) and similar styles of mineralization. Hopkins (1940) proposed a counter clockwise rotational reverse displacement of 17° for the Main break based on a pivot point near the west boundary of the Wright-Hargreaves mine. Wright (1979) proposed a counter clockwise rotational reverse displacement of 16° on the '04 break with a pivot point located near section 27E on the 5725' (1 745 m) horizon, well to the east of the Macassa number 3 shaft.

Mineralised Structures

'05 Break

The '05 break was discovered in the underground workings on the Macassa property in 1988. The break is located some 1 300 feet (396 m) to the north of, and sub-parallel to the '04 break (Figure 4.1). The initial discovery hole was drilled on the 5725' (1 745 m) level and intersected a gold-rich quartz vein system adjacent to a mylonitic fault 1005' (306 m) downhole (Kinross Gold Corp., 1996). Four subsequent holes were drilled to follow-up on the initial discovery with 3 of the 5 total holes intersecting ore-grade material. A fourth hole intersected low-grade, but highly anomalous gold values. To date, diamond drilling and development has defined the '05 break between the 4500' (1 372 m) and 7050' (2 149 m) levels between sections 20-37W.

The '05 break most commonly appears as a ¼-1" (0.6 -2.5 cm) wide chloritic ± molybdenum brecciated fault zone, but can also be much less pronounced appearing as a ¼" (0.6 cm) wide mylonitic seam or fault. The break dips steeply to the south between 70-80°. and strikes near 060°. Locally, the nature of the fault can vary from a ¼-1/2" (0.6-1.2 cm) chloritic fault with or without adjacent strong alteration and quartz veining (Figure 4.9A), to a strongly brecciated 1-3" (2.5-7.5 cm) wide chloritic-gouge filled fault with extensive bleaching, brecciation, mylonitization, and quartz mineralization (Figure 4.9B).

The '05 break structure is similar to many of the major mineralised structures in
Figure 4.9. Two photographs illustrating the varying nature of the '05 break. The top photo illustrates the '05 break from 7035.39 Sub No. 4, looking at the backs. The '05 break appears as a thin chlorite fault with a narrow quartz vein along the footwall contact. The host rock is basic syenite, and is largely unaltered. Mesh screen has 10 cm squares. The bottom photo shows the '05 break along the backs of the 6635.39 Sub No. 4. At this location the '05 break is a strong 2-5 cm brecciated chlorite healed mud fault with strong quartz veining and mineralisation hangingwall to the break. Notice the pervasive footwall alteration and deformation. Rock bolt plate is 12.5 cm wide.
the Kirkland Lake camp that occur as singular faults, but which commonly have sub-
parallel branches or splays. Mapping by the author revealed the branching nature of the
'05 break in the 7035.39 Sub No. 4. Mapping in the 6635.39 Sub No. 3 shows a much
less complex, singular '05 break structure (Figure 4.10).

The '05 break is hosted by a variety of different rock types, although basic syenite
and tuff are by far the most common host rock types. Conglomerate is a relatively scarce
host rock, but it was observed in the 7035 Sub No. 4 mapping location. There are no
significant strike lengths of the '05 break within porphyry.

Many of the mineralised zones of the '05 break occur within a tuffaceous unit.
This is likely due to the extremely brittle nature of the tuffs and resultant ease of
fracturing.

Apparent offset along the '05 break appears to be near 100' (30 m) in a reverse
movement (south side up) (McGregor, 1996). This reported offset is far less than that on
the '04 break and Main break (Table 4.1).

Although the '05 break was not defined underground until 1988 on the Macassa
property, the break has earlier been mined and developed in eastern portions of the camp.
The break appears to be continuous to the east, where it has been identified as the
Narrows break or No. 3 vein. At the Lake Shore mine, the No. 3 vein is located some 1
200 to 1 600' (366 to 488 m) north and sub-parallel to the Main break (No. 2 vein
zone) (Thomson, 1950). This structure can be traced along strike to the projected surface
exposure of the '05 break on Macassa property.

At Lake Shore, the No. 3 vein has many similarities to the '05 break including:
location nearly 1 200 to 1 400 feet (366 to 427 m) north of the main mineralised
structure; the same near vertical south dip; a similar strike near 060°: persistent but
irregular nature along strike; intermittent and irregular quartz mineralization; and
relatively minor development and mining compared to the Main break or '04 break.

Considerable development and definition drilling on the '05 break at Macassa
resulted in subsequent mining. Longhole mining was attempted that resulted in extensive
dilution in the host brittle tuff units and resulted in lower than anticipated grades. Total
mining on the '05 break in the mid-1990's yielded a head grade near 0.25 oz/t. This was
Figure 4.10. Geological mapping of the '05 break zone from the 6635.39 Sub No. 3. At this location, the '05 break occurs as a singular fault hosted entirely by tuff. Quartz veining and mineralization is located in both the footwall and hangingwall of the break. There are several late diagonal cross-faults that displace the break and mineralization.
well below anticipated grades that were forecast to be in the 0.35 to 0.45 oz/t range. At this grade, mining along the '05 break was uneconomical using gold prices of the period. No mining on the '05 break was resumed after the rockburst in April 1997.

As of January 1, 1998, the total reserves (diluted for mining) within the '05 zone are as follows: proven and probable 164 435t @ 0.30 oz/t, possible 11 743t @ 0.20 oz/t, and mineral inventory 10 241t @ 0.21 oz/t.

Mineralization

Mineralization related to the '05 break consists of quartz veining and flooding up to several feet in width in both the hangingwall and footwall of the break, but far more commonly occurs in the hangingwall of the break. Most mineralization consists of narrow quartz veins, less than 1 foot (30 cm) in width, which do not make ore. Visible gold is usually present in quartz-rich zones together with tellurides and 2-3% fine-grained disseminated pyrite. The '05 break zone may consist of several sub-parallel branches and splays with strong mineralization between the faults (i.e. 6035.39 Sub No. 3 mapping, Figure 4.8) as is the case at various locations along the '04 break. However, mineralization along the '05 break is also narrower, less continuous, and less extensive than along the '04 break. Microprobe analysis suggests that the gold is 3 times coarser, and that there is 3 times greater telluride content in '05 break related mineralization, compared to '04 break related ore (McGregor, 1996).

The '05 break ore material consists of relatively short strike length, narrow, distinctly plunging zones of mineralization with grades in excess of 0.25 oz/t over a 5.0' (1.5 m) horizontal mining width (Figure 4.11). This figure shows a series of en echelon mineralised shoots that are plunging steeply to the west. These mineralised shoots tend to have relatively short strike lengths compared to their lengths down plunge.

Several occurrences of pale green, 6-12" (15-30 cm) wide, felsic dykes have been observed adjacent to the '05 break in well mineralised areas. These dykes cross-cut quartz veining that is generally flanking the dykes. The dykes appear unmineralised although they are frequently sulphide-rich, containing up to 5% pyrite. Similar dykes have been observed adjacent to '04 break mineralization, such as in the 4729 area.
Figure 4.11. Longitudinal section of the '05 Break looking to the north (modified from Kinross files). This view clearly shows the high-grade narrow plunges of mineralization on the '05 Break.
Deformation

Analysis of the '05 break zone in thin sections and polished slabs reveals a structure with multiple generations of deformation. This deformation can be observed in Figure 4.12. Deformation consists of a mylonitic overprint on a crushed chloritic fault zone. The example shows deformed pyrite, secondary quartz mineralization, and a late extensional vein with a related weak fault that is perpendicular to the break. These observations suggest that an earlier mineralised structure was later deformed in a compressional regime.

Post-ore deformation is evident in host rocks adjacent to the '05 break in the 7035.39 Sub No.4 drift. In this area, pebbles within conglomerate footwall to the '05 break are deformed with the long axis of deformation parallel to the break zone (Figure 4.13). These deformed pebbles demonstrate that the compressional force \( \sigma_1 \) was acting perpendicular to the pebbles causing them to become deformed with an orientation similar to that of the '05 break zone. Extensional fractures in the pebbles parallel to the \( \sigma_1 \) stress indicate the \( \sigma_3 \) direction.

Another example of post-ore deformation is shown in Figure 4.14. Compressional stresses perpendicular to the fault plane have created boudinaged ribbons of quartz and altered fault rocks. Since the compressional forces are nearly perpendicular to the plane of the ore, the veins do not always appear folded by this later deformation. However, if ore shoots and quartz veins branch off the zone at oblique angles, they show evidence of the compressional event as a series of tight folds with the axial plane parallel to the fault plane (Figure 4.14). This compressional strain has an orientation consistent with that demonstrated by deformed conglomerate pebbles.

A series of post-ore sub-vertical faults bisect the mineralised '05 break zone at near 45° angles. Displacement along these faults is typically near 12" (30 cm) in a dextral manner. They show no evidence of being mineralised (Figure 4.15).
Figure 4.12. Polished slab of the '05 Break, from 6635.39 sub 4. This image clearly shows the '05 break as a sharp fault cutting hangingwall quartz veining and mineralization. Subparallel to the '05 break is a footwall mylonite consisting of sericite and pyrite. This deformation overprints a crushed chloritic fault zone. A late secondary quartz vein with a minor fault cuts through the '05 break with a minor offset visible.
Figure 4.13. Schematic sketch of pebbles in conglomerate from the 7035.39 Sub No. 4 in the immediate footwall of the '05 break. View is looking to the east. Note how the pebbles are flattened sub-parallel to the orientation of the '05 break, dipping about 75 degrees to the south. This deformation was caused by the principal compressional stress labeled Sigma 1. Tensional carbonate veins have developed at parallel to the principal compressive stress and are labeled Sigma 3.
Figure 4.14. Photos illustrating post-ore deformation along the '05 break. The top photo illustrates a portion of the '05 break with a broad zone of faulting and mineralization. Compressional forces have folded the entire zone giving it a wavy appearance. The view is looking to the east in 7035.39 Sub No. 4.

The bottom photo is a closeup of the top photo showing a folded quartz vein. The folded vein is at an oblique angle to the '05 break zone, but the vein sub-parallel to the '05 break zone does not show any visible deformation due to its orientation. The pencil is oriented sub-parallel to the '05 break.
Figure 4.15. Illustration of post-ore cross-faulting along the backs of the 6635.39 Sub No. 3. The sub-vertical cross-faults strike to the northeast / southwest, and offset quartz mineralization along the '05 break for up to 1 m. The mesh squares of the screen are 10 cm wide.
No. 6 Break

The No. 6 break is a major fault at Macassa that strikes near 070° and dips to the south between 45 to 55° (Figure 4.16). The fault strikes sub-parallel to the '04 break, but diverges slowly to the south to the east due to a difference in strike near 10°. The No. 6 break is typically a ¼” to 1” (0.5 to 2.5 cm) wide brecciated, chlorite-healed, strong fault/mud seam with strong chloritization, sericitization and silicification adjacent to the fault. Intense alteration and bleaching of the adjacent wall rocks are common, as are locally well-defined mylonitic structures. The No. 6 break may intersect any of the major lithologies at Macassa, however the break frequently forms a structural contact between basic syenite (footwall) and tuff (hangingwall). The No. 6 break can be traced across the entire Macassa mine property through Kirkland Minerals (Figure 2.11) and Teck-Hughes.

Another fault on the Lake Shore property dips to the south at 60° and displaces the South (No. 1) vein about 100' (30 m) in a reverse movement on the 1600' (488 m) level (Thomson, 1948). This reverse fault is likely of the same generation as the No. 6 break.

Extensive reverse faulting also occurs further to the east in the Wright-Hargreaves mine as shallow north dipping “strike” faults (see previous section, Figure 2.9). These north-dipping reverse faults likely formed later in the compressional regime as they are not mineralised and offset known mineralised zones.

The No. 6 break appears to roll off the '04 break just above the 4250' (1295 m) level near sections 30-40W at Macassa, and at higher elevations towards the east. On longitudinal sections, the plunge line of the intersection of the '04 break and the No. 6 break is near 10° to the west. It is not clear whether the No. 6 break rolls off a flattened section of the '04 break, or if the No.6 break actually offsets the '04 break. To date, there is no information on the north side of this junction that would indicate if the No. 6 break structure continues to the north of the '04 break.

Mineralization

Variable mineralization associated with the No.6 break includes dark greasy grey quartz fragments, distinct quartz veins sub-parallel to the break in either the immediate footwall or hangingwall of the break, and strong silicified hangingwall zones with 1-3%
Figure 4.16. Idealized cross-section of the Macassa Mine facing east at section 30W. The ‘04 Break flattens from near 70°S to near 50°S at the intersection with the No.6 Break. Where the two faults merge, ore has been mined between the two breaks in the 4232 stope in widths up to 15 feet (4.6 m).
disseminated sulphides. Generally, quartz, where present, is high-grade (frequently multi-ounce per ton values) with occasional visible gold and tellurides. Sulphide zones generally range from 0.10 to 0.30 oz/t over variable widths. Mineralised zones are usually within extensively bleached and altered zones.

Mineralization associated with the break is quite sparse compared to mineralised segments of the '04 break. Although not as extensively drilled as the '04 break, the No. 6 break has a less than 10% "hit ratio" (percentage of diamond drill holes intersecting ore values over mining widths) compared to a historical hit ratio of near 25% on the '04 break. Mineralised zones on the No. 6 break tend to have limited strike extents and occur as narrow mineralised shoots in longitudinal view.

The 4529.37 ore block is typical of mineralization on the No. 6 break. This block has a sharply defined, relatively narrow, ore plunge defined by high-grade diamond drill hole intersections. Outside the mineralised plunge, diamond drill holes have intersected extremely low-grade portions of the No. 6 break (Figure 4.17). The 4529.37 ore block was being mined in June of 1999 when closure was announced. Proven and probable diluted reserves on this block total 15 490 t @ 0.60 oz/t.

Mineralization associated with the break appears to be strongest near the intersection with the '04 break (such as the previously discussed 4529.37 block). However, this may be related to the fact that the No. 6 break is largely undrilled and unexplored especially at elevations below the 4250' (1 295 m) and 4500' (1 372 m) levels. The No. 6 break diverges from the '04 break at depth, so at deeper levels holes drilled from development on the '04 break become increasingly longer with increased depth below surface. From the 4250' (1 295m) level, the No. 6 break is generally less than 100' (30 m) in the hangingwall of the '04 break, but at the 4750' (1 448m) level it is about 600' (183 m) in the hangingwall of the '04 break.

Exploration drilling in 1997 defined a mineral inventory block on the No. 6 break near 14W section at the 4750' (1 448 m) elevation. Drilling in this area intersected mineralised sulphide zones in the hangingwall of the break, which are not as rich in gold as quartz associated with the break. The current resource on this zone stands at 7 620 t @ 0.29 oz/t. This zone is believed to be within the same plunge as the 4529.27 block, about
<table>
<thead>
<tr>
<th>4250' LEVEL</th>
<th>30W</th>
<th>28W</th>
<th>26W</th>
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<tr>
<td>-4300'</td>
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<tr>
<td>-4400'</td>
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<tr>
<td>4500' LEVEL</td>
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</table>

**4529.37 No. 6 BREAK ORE**
Longitudinal Section Looking North

**Figure 4.17.** Preliminary reserve longitudinal section of the 4529.37 No. 6 break block, looking to the north. Note the narrow plunge of the mineralised zone with the sharp contacts between ore and waste. Drill hole intersections are quoted in oz/t over horizontal mining widths in feet.
1500' (457 m) to the east. Follow-up drilling in 1998 along strike between these two zones had a drill hole intersect mineralization associated with the No. 6 break at 19W on the 4750' (1448 m) level. The narrow quartz zone contained visible gold and tellurides and assayed 1.81 oz/t over a 1.0' (30 cm) core length.

Further follow-up exploration drilling on the No. 6 break was on-going when closure of the Macassa Mine was announced in June 1999. Many of these intersections contained visible gold, and new sub-parallel zones were also discovered. The No. 6 break zone was encountered some 600' (183 m) to the south of the '04 break near the 4750' (1448 m) elevation. Intersections on this zone included 0.61 oz/t over 5.2' (1.6 m) (HMW, horizontal mining width) with visible gold. Additional new zones included an intersection of 0.76 oz/t over 12.8' (3.9 m) (HMW) some 400' (122 m) further south of the No. 6 break, and 0.48 oz/t over 5.0' (1.5 m) (HMW) including 2.24 oz/t over 1.0' (0.3 m), on another zone some 100' (30 m) south of the No. 6 break. The final chapter will discuss the exploration potential of this area.

Timing Relationships

In cross-section, the No. 6 break splays or rolls off the '04 break at a flattened section of the '04 break above the 4250' (1295 m) level (Figure 4.16). As there is no information to the north of this intersection, the true relationship between the two structures is difficult to ascertain. Two modes of formation of the No. 6 break may be envisaged. The No. 6 break may post-date the original formation of the '04 break. In this case, the '04 break would have pre-existed as a steep, likely normal, fault. During a later stage of compression, the No. 6 break could have formed as a 50° south dipping reverse fault intersecting the '04 break and reactivating the upper part. The '04 break appears to flatten in an area that is smeared along the contact with the 50° dipping No. 6 break. Alternatively, the No. 6 break may have formed as a flattening or horse-tailing splay near the termination of the '04 break. Subsequent fault movement could have extended the '04 break down to lower levels with the No. 6 break remaining as a discontinuous branch of the '04 break.

Lithological relationships are not conclusive to indicate reverse movement along
the No. 6 break. However, the dip of the structure, and style of mineralization along the No. 6 break is suggestive of a reverse fault system. The No. 6 break does appear to offset the top of the anticlinal vein at Kirkland Minerals in a reverse movement (Thomson, 1950). A reverse fault does not open as easily as a normal fault to permit the flow of hydrothermal fluids. This could explain for intermittent mineralization, and mineralization that is in both the hangingwall and footwall of the No. 6 break.

The reverse faulting regime does not appear to be as economically important a mineralising period as the pre-existing sub-vertical extensional faults. The later reverse faulting likely remobilised gold from the earlier normal faulting period of mineralization and introduced relatively small amounts of new mineralization. Remobilization of gold could explain why the No. 6 break is best mineralised in close proximity to the '04 break. However, the down-dip extensions of the No. 6 break have been sparsely explored. Alternatively, the junction of the two structures may have acted as a conduit for mineralising fluids.

Mineralization between the two structures is evident in the 4232 stoping area. In this stope, mineralization in the hangingwall of the '04 break is confined by the No. 6 break. The 4232 stope is located above the 4250' (1295 m) level where ore is shown in the wedge of ground between the '04 break and the No. 6 break (Figure 4.16). Mineralization continues from break to break but is not consistent and is characterised by low-grade silicified, sulphide-rich zones with intermittent zones of quartz fragments and discontinuous veins. Only localised areas have mineralization continuing into the hangingwall of the No. 6 break. At greater depths below this stope, the No. 6 break dips further away from the '04 break and the two zones collectively are not well enough mineralised to make ore.

Between the No. 6 break and '04 break "hangingwall" vein systems are common. These hangingwall veins have a variety of different orientations and styles of mineralization, and are discussed in detail in a subsequent section. These veins are most commonly flat, south-dipping quartz veins (i.e. 4719 complex), or steep to sub-vertical south (i.e. 4524.32 LH) or north (i.e. 4526 PCF or 4528 PCF) dipping quartz veins. All of these different vein types are usually very well mineralised.
Related Significant Structures

North Break

The North break is a major structure located less than 100' (30 m) to the north of the '04 break in the lower levels of Macassa below the 5725' (1 745 m) level. In this area of the mine, the fault strikes sub-parallel to the '04 break near 060° and is sub-vertical (Figure 4.1, Figure 4.5). The North break is a mine-wide scale, chlorite-gouge fault generally from 1/8" to ½" (0.3 to 1.3 cm) thick and possessing limited alteration of adjacent wallrock. The fault is not ore-bearing, but in places may act as the northern faulted contact for wide areas of breccia ore located in the footwall of the '04 break.

The North break is not always discernible from the similar Footwall fault. This sub-parallel structure also occurs to the north of the '04 break at the lower levels of the mine. When two faults are present to the north of the '04 break, the most northerly is the North break, with the Footwall fault closest to the '04 break (Figure 4.5). When only one fault is present to the north of the '04 break, it is generally referred to as the North break.

The North break and/or the Footwall fault act as the northerly contact of important pockets of wide breccia ore between section 20W and 25W between the 5700' (1 737 m) and 6300' (1 920 m) levels and also between section 33W to 38W between the 6100' (1 859 m) and 6400' (1 951 m) levels. In these areas, ore footwall to the '04 break is bounded to the north by the North break (Figure 4.5). The rocks north of the fault are significantly less altered and unmineralised.

The boundary that separates the traditional Macassa "Upper Beat" and "Lower Beat" is located between the 5600' (1 707 m) level and 5725' (1 745 m) level. Between these levels, there appears to be some confusion in the naming of the various structures. The North break from 5725' (1 745 m) level and below appears to be named the '04 break on the 5600' (1 707 m) level and above. Similarly, the '04 break on the 5725' (1 745 m) level and below appears to be named the South break on the 5600' (1 707 m) level and above. A cross-section through this area (Figure 4.1) reveals an apparent transfer of ore to the southern of the two breaks from the northern break between these levels. The Lower Beat structure that appeared mineralised was probably termed the '04 break to correlate with the mineralised '04 break on the upper levels. Despite the apparent
confusion in the naming of structures, there may also be considerable exploration potential if the '04 break is in fact the North break on the lower levels. There appears to be no mineralization along the North break ('04 break) in the Lower Beat. If a transfer of mineralization from the footwall structure to the hangingwall structure occurs down-dip, a broad zone of mineralization and subsidiary veins may be located between the two structures. Similar mineralised zones exist between the '04 break and the Main break crossover area at the east of the mine.

Footwall Fault

The Footwall fault is a mine-wide scale fault located sub-parallel to and in the footwall of the '04 break in the lower levels of the Macassa mine from the 5725' (1 745 m) level to the 7050' (2 149 m) level. The fault is likely a splay off the '04 break, as the fault appears to roll off or splay from the '04 break near section 34W on the 6750' (2 057 m) level. The footwall fault occurs as a 1/8" to ½" (0.3 to 1.3 cm) wide chlorite-gouge filled fault with a dip between 58-78°S. The fault is well pronounced but does not have a wide zone of brecciated gouge with pervasive bleaching and alteration as is characteristic of the '04 break. The fault is the first fault to the north of the '04 break at these levels, generally approximately 50' (15 m) away. Further to the north, and sometimes conforming or joining together with the Footwall fault along strike, is the North break.

The Footwall fault is not an ore-bearing structure. Although not mineralised, the Footwall fault is an important fault in the lower levels, as it acts as the northern boundary to extremely wide zones of breccia ore, confined to the south by the '04 break. These zones have widths up to 50' (15 m) or greater. A classic example of this occurs in the 6733 area where the Footwall fault bounds a section of breccia ore that is near 50' (15 m) wide (Figure 4.5). In this example, the Footwall fault acts as a sharp northern contact to breccia ore, and when the fault rolls back into the '04 break, the lens or pocket of ore created between the two faults is pinched out. This example also shows the North break as a second sub-parallel structure to the north of the '04 break. However, only the Footwall fault appears to be influencing mineralization. The North break and Footwall fault are likely representations of a sub-parallel fault to the north of the '04 break that locally splays into multiple branches.
South Break

The South break is a major structure above the 5725' (1745 m) level at the Macassa mine. The structure has been mined between the 5025' (1532 m) and 5700' (1737 m) levels west of the Tegren cross-fault. The South break is a break-like structure with a characteristic brecciated fault zone and a \( \frac{1}{4}'' \) to 2'' (0.6 to 5 cm) mud fault seam occurring with minor faults and slips in an area usually less then 2 feet (60 cm) wide. The fault strikes sub-parallel to the '04 break at near 060° and dips near 70°S (Figure 4.1). The fault is located on average 50' (15 m) to the south and in the hangingwall of the '04 break.

The South break is not present below the 5725' (1745 m) level (Figure 4.1). Below this level the structure appears to continue as the '04 break. The two faults are likely the same structure, and the '04 break term is used below the 5725' (1745 m) level because it is the structure most commonly associated with break ore.

Mineralization associated with the South break generally consists of footwall zones of brecciated and fractured quartz and silicification usually less than 3' (1 m) wide. Sulphides, chiefly pyrite, are ubiquitous, with up to 5-7% in strongly silicified zones. The grade of ore zones is typically near 0.50 oz/t over narrow (~5.0', or 1.5 m) mining widths.

The South break may also form the sharp southern contact to wide zones of breccia ore. These economically important zones are confined to the north by the '04 break and may exceed 50' (15 m) in width (similar to the breccia ore zone bounded by the '04 break and the Footwall fault in Figure 4.5). These breccia zones have historically been a significant source of ore tonnage at Macassa, because of their exceptional widths and good grades.

Several high-grade hangingwall veins were mined in 1999 near section 30W on the 5025' level between the mined-out 5030 stope ('04 break ore) and the South break. A portion of ore is in reserves in the footwall of the South break in this area. All three zones are individually ore, but collectively across the three zones, the grade is not high enough to make ore (breccia ore would be continuous mineralization at ore grades). The quartz veins between the breaks have a variety of different orientations from near-flat to steeply south dipping. The veins have characteristics differing from sharp bounded continuous
quartz veins to irregular zones of quartz fragments and stringers. The host tuff and porphyry between the breaks shows reddish brown alteration. The veins and mineralization formed in an area of heavily fractured rock. This fracturing created the permeability through which large volumes of hydrothermal fluids could circulate to cause the strong alteration and mineralization. The resultant mineralization represents a weak "breccia ore" zone that is not sufficiently mineralised to make ore.

Crossover faults between the South break and the '04 break (Figure 4.18) acted as conduits for mineralising fluids and host distinct vein-type mineralization. As these crossover faults may have acted to channel hydrothermal fluids, they are not associated with wide, irregular zones of breccia ore.

Other Mineralised Structures

North Porphyry Zone

The North Porphyry Zone (NPZ) is located approximately 400 feet (122 m) to the north of and sub-parallel to the '04 break on the 4500' level (Figure 4.16), which saw limited development at the end of a cross-cut north of the '04 drift. The NPZ has a defined strike length of nearly 500' (152 m) and a vertical extent of near 200' (61 m). Mineralization consists of a series of quartz stringers, silicification, and ubiquitous sulphides associated with a fault system striking near 060° and dipping to the south at 50°. The zone is hosted by syenite porphyry.

Mineralization along the North Porphyry Zone is different than the massive quartz veining along the '04 break. Diffuse zones of silicification or quartz stringers are typically 3-5' (0.9-1.5 m) wide and grade near 0.30 oz/t over mining widths in excess of 5.0' (1.5 m). Limited mining on the NPZ in 1995 in the 4530 TDB produced 1 338t @ 0.18 oz/t. This lower grade was largely due to excessive dilution. The area was mined at widths near 10.0' (3 m) on a mineralised zone only 5.0 - 7.0' (1.5 - 2.1 m) wide.

Exploration on the NPZ to date has been limited. In the 1998 drilling program a diamond drill hole yielded 0.91 oz/t over 5.0' (1.5 m) HMW (horizontal mining width) while another intersected a wide zone of 0.19 oz/t over 30.0' (9.1 m) (HMW). Down dip from the 4500 Level, the flatter dip of the NPZ indicates that it may merge with
Figure 4.18. Plan view of the 5600' (1,707 m) Level showing the '04 Break, South Break and crossover faults. The crossover faults are associated with mineralised quartz veins between the two major breaks. The crossover faults generally dip steeply to the east between 65° and 85°. Areas of mining between the two breaks are often subject to seismic events along these crossover faults.
the '04 break (Figure 4.16). It is possible that higher-grade mineralization will be encountered at the intersection between the NPZ and the '04 break (similar to the highest-grade mineralization along the No. 6 break as it approaches the '04 break). The 1999 Macassa resources (diluted to represent typical mining) on the NPZ were calculated at 13 486t at a grade of 0.250oz/t.

**Hangingwall Veins**

**Introduction**

The diverse range of mineralised quartz veins that occur in the hangingwall (south) of the '04 break or Main break structures are collectively known as hangingwall veins. These veins contribute a significant portion of the Macassa ore reserves. As with the other six mines in the camp, the importance of hangingwall veins at Macassa increases as the major break structures (i.e. '04 break, Main break) are mined out.

Recent 1999 reserves indicate that different forms of hangingwall veins collectively account for more than 40% of total reserves (Table 4.2). This table breaks down the hangingwall veins into two distinct classes. Veins with a XXXX.X2 designation represent mineralization that is usually within 20' (6.1 m) of the '04 break and is usually sub-parallel to the break and can be mined as a wide zone right to the '04 break (as is the 4528.32 and 4721.32 blocks). Hangingwall veins that generally have flatter dips than the '04 or Main break structures, and are distinctly separate structures are given a XXXX.X7 designation (such as the flat veins in Figure 4.8).

The tonnage of hangingwall stopes is quite variable. One of the largest hangingwall veins mined at Macassa was the high-grade 4719.37 complex. Pre-mining reserves on this vein were nearly 60 000 t @ 0.71 oz/t. This vein is actually the same zone as the 4524.37 block which has been faulted up by the Tegren cross fault. Typically, hangingwall vein reserve blocks are near 5 000 tons with grades near the mine-wide reserve grade of 0.48 oz/t. However, hangingwall veins with richer grades approaching 1.00 oz/t are common.

Hangingwall veins are generally 1" to 3' (2.5 cm to 1 m) wide quartz veins with high-grade gold mineralization. Mineralization frequently consists of visible gold and/or
1999 Macassa Reserves By Type

<table>
<thead>
<tr>
<th>MINERALIZATION TYPE</th>
<th>TONS</th>
<th>GRADE</th>
<th>CONTAINED</th>
<th>PERCENT</th>
<th>PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(oz/t)</td>
<td></td>
<td>(ozs)</td>
<td>(Contained ozs)</td>
<td>(Total tonnage)</td>
</tr>
<tr>
<td>04 Break Ore (i.e. 3829.30)</td>
<td>357,397</td>
<td>0.49</td>
<td>175,863</td>
<td>46.6%</td>
<td>45.1%</td>
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<tr>
<td>Immediate Hangingwall Ore (i.e. 4721.32)</td>
<td>145,788</td>
<td>0.46</td>
<td>67,408</td>
<td>17.9%</td>
<td>18.4%</td>
</tr>
<tr>
<td>Central Ore Zone (between breaks, i.e. 5330.34)</td>
<td>51,608</td>
<td>0.34</td>
<td>17,332</td>
<td>4.6%</td>
<td>6.5%</td>
</tr>
<tr>
<td>Footwall Veins (i.e. 5019.35)</td>
<td>38,322</td>
<td>0.55</td>
<td>21,224</td>
<td>5.6%</td>
<td>4.8%</td>
</tr>
<tr>
<td>South Break Ore (i.e. 5326.36)</td>
<td>16,434</td>
<td>0.48</td>
<td>7,898</td>
<td>2.1%</td>
<td>2.1%</td>
</tr>
<tr>
<td>Hangingwall Veins (i.e. 4722.37)</td>
<td>181,134</td>
<td>0.48</td>
<td>87,290</td>
<td>23.1%</td>
<td>22.9%</td>
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<tr>
<td>Others (i.e. 4201.21)</td>
<td>1,260</td>
<td>0.39</td>
<td>492</td>
<td>0.1%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Total (3800-5700 and Shaft Zone)</td>
<td>791,943</td>
<td>0.48</td>
<td>377,507</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 4.2. Tabulation of the 1999 Macassa Mine reserves by mineralization type.
tellurides. Wallrock adjacent to the vein usually is barren except where zones of silicification or sulphides exist. Assays in the multiple ounces per ton on the vein are common. Veining may occur in all rock types, and multiple rock types may host a single vein. However, veins are generally in proximity to the intrusive stocks. The veins may dip from near flat to sub-vertical, and generally are flatter than the main break structures. All hangingwall veins at the west end of Macassa mine terminate against the '04 break. The flatter veins steepen and roll into the break up dip, while steeper hangingwall veins may roll into the '04 break either up or down dip. Veins typically dip to the south but north-dipping veins are also present. Parallel sets of narrow, high-grade north-dipping veins are frequently located in the wedge of ground between the '04 break and the No. 6 break (i.e. 4526.27 and 4527.37 veins: Figure 4.16).

Hangingwall veins typically occur near a bend or roll in the '04 break and will diverge from it along strike at angles usually less than 30º. Veins are frequently located in the wedge of ground between two major faults, as in the case of the area between the '04 break and the Main break (Figure 4.8), and between the '04 break and the No. 6 break (Figure 2.11; Figure 4.16).

Hangingwall veins are primarily quartz with varying carbonate minerals, actinolite, wallrock fragments, sulphides, tellurides and fine native gold (Kinross. 1996). Multiple generations of quartz are generally present in the same vein structure with varying shades of white to dark grey quartz. Mineralization is in the form of fine-grained native gold and tellurides (Thomson, 1950). Visible gold and tellurides are usually along tight slips along vein margins, in inter-vein quartz seams, or in nests up to several mm in diameter associated with pyrite.

Orientations of hangingwall veins can be highly variable and complex. However, the flattest portions of hangingwall veins normally have the highest grades. Veins that change dip from flat to steep as they converge with the '04 break will generally show a decrease in grade at the steeper orientations. This is demonstrated by veining in the 4719.37 complex (Figure 4.19). The vein has the highest grades in the 0º-30ºS flat-dipping southern portion of the vein. To the north, grades drop significantly as the vein steepens to near 50ºS, as it approaches the '04 break.
Figure 4.19. Three-dimensional view looking to the northeast of the 4719 complex. This flat vein has a rolling nature with localized folding and faulting. The average dip of the vein is near 30° to the south, but the dip increases up-dip towards the '04 Break (north) and down-dip towards the No. 6 Break (south). Image modelled from a wireframe completed in Datamine by A. Lauzon.
Gold appears to have been deposited late in the formation of the veins. At a microscopic scale, quartz veins show signs of preferential alignment and growth of quartz perpendicular to vein walls (Figure 4.20). This indicates open space filling in an extensional environment. Macroscopically, quartz hangingwall veins frequently have a braided or ribbon-like appearance. This provides evidence of multiple phases of quartz veining (Figure 4.21). Other quartz veins show examples of hydrothermal brecciation suggestive of the high fluid pressures and explosive and implusive nature of the mineralising hydrothermal fluids (Figure 4.21).

Alteration adjacent to hangingwall veins generally appears very weak or non-existent in comparison to typical brecc alteration. Quartz veins generally overprint earlier local sericitization, carbonatization and chloritization of adjacent wall rocks. Hangingwall veins are usually associated with thin chlorite-or molybdenite coated faults or slips. This likely represents the original fracture or fault that was altered, then mineralised and then reactivated along the original plane of weakness.

**Deformation**

Evidence of various forms of deformation can be observed in all hangingwall and footwall veins at Macassa. One of the most obvious forms of deformation, and most important and problematic to mine geologists, is post-vein faulting which occurs on all scales with displacements ranging from a few millimetres to over a thousand meters along the '04 break. Sharp and tight chlorite slips or faults where displacement is generally less than 10 cm are very common (Figure 4.22). Faulting is generally along steep oriented structures. The faults dip between 60° to 70° either north or south with movement usually in a reverse direction. Slips or faults that may appear as no more than hairline cracks may cause displacements up to 3 m or more, usually in a reverse direction. The strike of these late cutting faults is quite variable, but they are generally aligned nearly perpendicular to the '04 break, thus striking near north-south. Late cross-faulting is particularly common in the 4719.37 flat vein complex. Several cross-faults were observed during mining in this area. Each fault usually displaces the main vein by less than 2 m. Identification of these late faults and knowledge of the resultant displacement on vein is an important step.
Figure 4.20. Photomicrograph of the S3 hangingwall vein from the 4250' (1295 m) Level. Note how the quartz grains of the vein have a preferential growth orientation from the host rock contact. This indicates that the quartz crystallized in an extensional setting. The host rock at the bottom of the image is fine-grained ash-flow tuff. Crossed nichols. Width of view is 14 mm.
Figure 4.21. Various forms of hangingwall quartz veining at Macassa.
TOP. 4710 hangingwall vein, looking at the backs. The image shows multiple generations of quartz veining forming a braided and branching network. Note the flame-like lenses of quartz. Rock bolt plate is 8" (20 cm) across.
BOTTOM. 4721.32 stope, looking at the backs of strongly brecciated multi-ounce quartz veining some 20' (6m) hangingwall to the '04 Break. The altered wallrock fragments within the vein are basic syenite. Hydrothermal fluids that deposited the quartz and gold have explosively been injected into the host rock causing brecciation. 6" (15 cm) pencil for scale.
Figure 4.22. 4518.37 stope, facing west. This view of 4518.37 hangingwall vein shows the main lead vein at the top of the image with several thinner sub-parallel quartz veins and stringers underneath. The vein system dips to the south at 43°. There is a chlorite fault along the hangingwall of the vein marking a sharp contact with the fresh basic syenite host rock. Several late slips perpendicular to the vein have offsets less than 10 cm. Hammer is 30 cm long.
to keeping the mining crews advancing on the veins and to minimise dilution.

Small-scale slips or faults related to vein emplacement may be reactivated and sharply cut the mineralised veins. The 4518.37 hangingwall vein is sharply bounded by a chlorite-molybdenite fault, which parallels the vein along its strike causing numerous terminations of the vein against the fault. This creates a major dilution and grade problem as there are stretches over several meters where the vein has "pinched" out before it re-emerges further along strike.

Mineralised veins are commonly cut or faulted by major structures such as the '04 break. There are no known locations in the current mine workings where a mineralised vein actually crosses a break or even a major fault without offset. Typically, the veins will begin near a bend or a roll in the '04 break, and will diverge at angles usually less than 30°. The S3 vein on the 4250' (1295m) level is a classic example of a hangingwall vein being sharply terminated by a break structure, in this case the S break.

Larger-scale significant cross-faults also cut mineralised hangingwall veins. The Tegren cross-fault cuts all mineralised structures and veins at the mine including the 4719.37 hangingwall vein complex. The Tegren fault offsets the western margin of this block up some 250' (76 m) and some 200' (61 m) to the south. The faulted western portion of the 4719 complex was mined as the 4524.37 block.

Sets of chlorite and/or molybdenum coated slips or faults within mineralised vein structures frequently show pronounced slickensides and evidence of small-scale movement. These generally sub-vertical slickensides formed along the reactivated fractures or faults that the mineralising fluids used as conduits during hydrothermal activity and original vein formation.

In addition to being faulted, hangingwall and footwall veins are also commonly folded. A wireframe of the 4719.37 flat vein complex shows the rolling and undulatory nature of the "flat vein" (Figure 4.19). This localised rolling was not initially anticipated when the block was first defined with diamond drilling only. Local rolls and folds can cause the vein to dip from 0° to 50° S in a single cut, with the average dip usually near 30° S. At the margins of the block, the vein steepens as it rolls up into, and is then cut by, the '04 break to the north. To the south it steepens down-dip before terminating against
the No. 6 break. On the western margin, the vein steepens in dip to near 45° W and, on the east, the vein steepens to over 60° E.

The 4206 S1 and S3 veins are other clear examples of folded quartz veins. Figure 4.23 shows a sketch from a series of photos of the S1 and S3 veins at their point of intersection (encountered during mining in 1996). There are clearly multiple generations of quartz veins, all of which have been folded and deformed.

Folding is also apparent on a stope-sized scale in hangingwall veins with two prominent examples. The S2 vein on the 4250' (1 295m) level of Macassa near Section 8W is folded into an antiform with the axis plunging 026° south-east (Watson, 1984). Thomson et al., (1950) described a similar vein on the 4450' (1 356 m) level at Kirkland Minerals. The S2 vein at Macassa crosses host intrusive rocks and layered tuffs and shows no preferential orientation to bedding in the tuffs. Watson (1984) suggested that the vein formed along a curvilinear fracture plane, but it is more likely that the vein formed at a steep oblique angle to the strike of bedding in the tuffs and the long dimension of the intrusive. At this orientation the vein could have been folded by late compressive forces which were near perpendicular to the orientation of local bedding.

Folding is also evident in more steeply dipping veins. This folding is not always as readily identifiable as the veins are oriented nearly perpendicular to the late compressive forces. Steep hangingwall veins will have a boudinaged or "pinch and swell" nature due to these late compressive forces. Figure 4.24 shows the 4520.32 stope with boudinaged 60°S dipping quartz veins located about twenty feet in the hangingwall of the '04 break. The photo also shows a number of smaller veins with tight folding. These veins were likely emplaced as part of a broader stockwork of veins with differing orientations. During late compressional deformation the sub-vertical veins were boudinaged, while the smaller veins at oblique angles were folded and deformed into a narrower zone of roughly sub-parallel veins.
Figure 4.23. Sketch of the backs in the 4206 stope area, showing folded quartz veining (in black) at the intersection of the S1 and S3 veins. Top of image is against the SE wall, bottom of image is against the NW wall. Rock bolts covers can be used for scale (10 cm).
Figure 4.24. Photograph of the 4520.37 stope, facing east. The image shows a zone of quartz veining some 20’ (6.1 m) in the hangingwall of the ‘04 Break. The larger quartz vein to the left of the image has been folded and boudinaged. Smaller veins show evidence of folding and “pinch and swell” characteristics. These characteristics are evidence of post-mineralization compressional deformation. Hammer for scale.
Footwall Veins

Any of the many quartz veins or stringers located on the footwall side (north) of the '04 break (or the Main break at the east end of Macassa) are collectively grouped as footwall veins. Footwall veins are far less important than hangingwall veins, both in terms of numbers of veins and contained ounces (Table 4.2). However, the overall mine-wide reserve grade for footwall veins is higher than the overall mine-wide reserve grade. By far the largest single footwall vein block is the 5019.35, which contains a diluted reserve of 21,255 tonnes at 0.59 oz/t (1999 reserves).

Within the most recent Macassa working areas, footwall veins are generally narrow quartz stringers and veins ranging from 2 to 60 cm in thickness. They typically have strike lengths less than 100' (30 m) and dip lengths also less than 100' (30 m). They strike at oblique angles to the '04 break at angles from 5° to 40°. The dip of the veins can be divided into three main groups: 1) sub-vertical to south-dipping veins which run sub-parallel to the '04 break; 2) gently south dipping veins which roll into the '04 break; and 3) north dipping veins which terminate against the '04 break.

Footwall veins are typically located along a thin chlorite-coated slip or fault on either the footwall or hangingwall of the vein. Footwall veins terminate against the '04 or Main break. They do not appear as a branching or braided structure of the break. In thin sections, the quartz veins appear to have sharp margins with adjacent wallrock with weak chlorite and sericite alteration along the margins. In hand samples many of the footwall veins appear to have very limited associated wallrock alteration, quite unlike the pervasive alteration along the '04 break.

An examination of ore-grade and low-grade footwall veins revealed the presence of several different generations of quartz. Low-grade (waste) quartz veins tend to have the least altered wallrock margins and sharp vein contacts. This barren quartz has less sulphide minerals (mainly pyrite), and any pyrite that is present is usually euhedral. The barren quartz is also typically coarse grained and has less carbonate minerals. Colour cannot be used to identify barren or mineralised quartz. Sampling and assaying are the only reliable methods of separating ore and waste.

The relationship of hangingwall veins being fairly common relative to footwall
veins at Macassa is reversed at the eastern end of the camp, where footwall veins are ubiquitous and more common than hangingwall veins (Thomson, 1950).

**POST-ORE FAULTING**

**'04 North Break**

The '04 North break is a post-'04 break ore reverse fault which strikes between 050°-090° and dips to the south at 25-55°. It has been traced for more than 4000' (1 219 m) along strike from near 2 East section on the 6575' (2 004 m) level at the east end of the mine, to west of the Number 3 shaft across the mine property. The '04 North break has been observed in mapping and diamond drill holes in the lower levels of the mine from the 6450' (1 966 m) level down to the 7050' (2 149 m) level, and in drill holes beneath the 7050' (2 149 m) level. Between sections 0 West to 40 West, it truncates and offsets the '04 break at depths between 6450' (1 966 m) and 6975' (2 126 m) (Figures 4.25 and 4.26).

The dip of the '04 North break shows a general flattening with depth. Figure 4.25 shows a series of cross-sections of the '04 North break from 20-40 West, and Figure 4.26 shows simplified sections from 10 East to 15 West. Sections 20-40 West reveal that near the 6600' - 6700' (2 012 - 2 042 m) levels, the fault dips at 40-50° S, but at depths near the 7050' (2 149 m) level the dip has generally flattened to near 25-35° S. Flattening down-dip is a feature that is characteristic of many thrust faults.

Further east in the mine, details of the '04 North break are not as well-known. The strike appears to change to the north, causing the break to swing away from the '04 break. On sections 5 East and 10 East, the '04 North break shows an apparent steepening in the sections shown as the strike of the fault swings more to the north.

Sections 5 and 10 East also show a steepening of the '04 North break to the west. On 20 West section, the dip of the '04 North break ranges from approximately 38° S near the 6600' (2 012 m) level to 23° S near the 6900' (2 103 m) level. On 40 West section the dips are steeper, ranging from 50° S on the 6750' (2 057 m) level to 42° S on the 7050' (2 149 m) level.

The variability of dip along the '04 North break is consistent with rotational or
Figure 4.25. Idealised cross-sections showing displacement of the '04 break by the '04 North break from section 40W to 20W.
Figure 4.26. Idealised cross-sections showing displacement of the '04 break by the '04 North break from sections 15W to 10E.
scissor-like fault movement. Figures 4.25 and 4.26 show a reverse offset along the '04 North break (using the '04 break as a marker) of 58' (18 m) at 40 West (south or hangingwall side up). The offset increases significantly to the east to 171' (52 m) at 20 West, and to 281' (86 m) at 5 West, also with reverse movement.

As seen from fault striations, the horizontal displacement component along the '04 North break appears to be insignificant. Slickensides on the fault surface are aligned sub-parallel to the dip direction of the fault. Ore blocks related to the '04 break show no significant displacement along strike. The 6723 block is offset some 180' (55 m) down-dip by the '04 North break until it continues as the 6922 block. Despite this sizeable offset, longitudinal sections of the ore show minimal horizontal offset.

The line of intersection between the '04 break and the '04 North break plunges to the west. From sections 20 West to 40 West the top intersection with the '04 break ranges from 6645' (2 025 m) to 6895' (2 102 m) respectively, a vertical difference of 250' (76 m) (Figure 4.25). However, the Tegren cross-fault intersects the '04 North break between this interval, and has a vertical offset of 200' (61 m) (west side up) (Ball, 1984). This suggests that the vertical change is approximately 450' (137 m) over the 2000' (610 m) interval between sections prior to displacement by the Tegren cross-fault. This equates to a westerly plunge of 13° of the line of intersection between the '04 break and the '04 North break. To the east, this line of intersection plunges steeply to the east, corresponding to the change in strike to the north of the '04 North break.

The nature of the '04 North break is variable, depending on the host rock type. At most locations, where the host rock is basic syenite, felsic syenite, or porphyry, the '04 North break occurs as a bleached mylonitic fault usually 0.1 to 2.0 cm wide (Figure 4.27). At some locations the break occurs as two similar sub-parallel faults or branches, such as observed in the 6928 bored raise. The break shows well preserved examples of ductile deformation including shear bands. Generally the fault zone is greenish to orange due to strong sericitization, chloritization and hematite staining.

Slightly more brittle behaviour with a strongly altered zone is shown in a fresh brick red porphyry on the 6600' (2 012 m) level drift east of the Tegren fault. At this location, the '04 North break dips 36° S and shows extensive footwall hematite alteration.
Figure 4.27. Nature of the '04 North Break at Macassa.
TOP. View of the west face of the 6934 forward showing the '04 North break. At this location the '04 North Break dips to the south at 45° in locally fractured basic syenite. Localized bleaching and numerous chlorite fractures occur in the footwall. The '04 break is approximately four feet (1.2 m) to the south.
BOTTOM. View of the '04 North break facing west on the 6600 Level near 30W. The break exhibits local crushing and brecciation and dips 36° S. The structure is within brick red syenite porphyry with locally strong hematite alteration. Localized quartz stringers and silicification can be observed on the hangingwall side of the structure. Rock bolt cover plate is 5" (12.5 cm) wide.
extending for near 30 cm. and less intense hangingwall alteration extending for 2-5 cm (Figure 4.27). At other locations, in conglomerate and tuff units, the break typically appears as no more than a hairline chlorite slip or minor fault with little alteration or bleaching. In these rock types, the '04 North break shows characteristics of brittle deformation. The '04 North break appears as a 30° S dipping thin chlorite fault in conglomerate in the 7038 cross-cut. This variable and subtle nature of the '04 North break makes correlation of the structure across discontinuous exposures extremely difficult.

The '04 North break commonly has felsic syenite along the footwall (north of the break). This suggests a preferential formation along lithological contacts. However, the contact is not only along the felsic syenite. In the 6928 by-pass drift the break developed along a basic syenite- syenite porphyry contact. These lithological contacts may have provided convenient locations for fluid migration, which facilitated fault movement.

While generally unmineralised, the '04 North break is locally silicified with minor quartz veining. Typically the break zone has above background levels of gold between 0.02 oz/t to 0.04 oz/t. In the 6928 by-pass drift, 2 grab samples of a silicified breccia zone surrounding the break both returned assays of 0.02 oz/t. At this location, silicification forms a fine-grained milky white matrix with minor quartz fragments, altered wallrock fragments and trace amounts of sulphides (chiefly pyrite). In the 6934 SDE, a grab sample of the '04 North break, occurring as a 2-5 cm mylonitic bleached and altered buff-green fault, returned an assay of 0.04 oz/t.

Occasionally more extensive quartz veining is associated with the '04 North break, such as observed in the west face of the 6934 SDW (Figure 4.28). At this location a 2-5 cm dark grey cherty - looking quartz vein is located in the footwall of the break. A grab sample from this quartz vein returned a gold assay of 0.22 oz/t. This quartz appears to be a later generation of quartz than that associated with the '04 break approximately 60 cm to the south at this location.

A late series of minor, north-dipping faults offsets both the vein and fault (Figure 4.29). This north dipping fabric is related to larger-scale, steeply north dipping faults that cut the '04 North break in the same sub-level.
Figure 4.28. 6934 stope ore development, west face. The 75°S dipping '04 break forms the hangingwall of the drift (left side of figure). South of the '04 break is syenite porphyry with basic syenite to the north. The 2-3’ (0.6-0.9 m) wide zone of quartz veining in the footwall of the '04 break is ore-grade. The '04 break and the quartz veining are cut by the 40°S dipping '04 North break. Fault drag visible within the quartz veining is consistent with reverse movement on the '04 North break. The weak quartz veining in the footwall of the '04 North break is of a later generation than the veining associated with the '04 break. Grab samples from this quartz assayed only 0.22 oz/t on the vein material. HI stick is 2.5’ (0.75 m) long.
Figure 4.29. Quartz stringer in basic syenite in the immediate footwall of the '04 North break. Closeup of Figure 4.28 from the west face of the 6934 FWD. Image shows brittle deformation of the quartz stringer along a thin slip. Note also the extensional quartz-carbonate filled fractures appearing as white lines within the vein. The '04 North break is located just above and sub-parallel to the quartz stringer shown. Scale is in tenths of a foot (1 foot = 0.3048 m).
Timing Relationships

Detailed geological mapping at the 1" = 10' scale has been completed by the author in parts of the 6934 FWD sub-level in order to establish the relative timing and nature of faulting in this area (Figure 4.30). Four major generations of faulting can be recognised: the Tegren cross-fault (just to the east of the mapping shown); north-dipping reactivated faults; the '04 North break; and the '04 break.

The most recent major fault in this area is the Tegren cross-fault which is a steeply east dipping fault that sharply truncates both the '04 break and the '04 North break. A pronounced and well developed steeply north-dipping fault, together with related sub-parallel minor faults and splays all dipping ~ 80-85° N have been mapped in the 6934 FWD sub-level (Figure 4.30). This 0.5 to 2.5 cm wide chloritic fault is referred to as the North break at various other locations in lower levels of the mine. This sub-vertical fault or fault system is sub-parallel to the '04 break and likely formed syngenetically with the '04 break under similar stress conditions. However, at this location, the North break is definitely truncating and displacing the '04 North break. Face mapping in the 7038 CUC also shows the '04 North break offset by a north-dipping, sub-vertical fault less than 5 feet (1.5 m) north of the '04 break. Offset calculations along this north-dipping fault (Figure 4.31) reveal a vertical offset of 7.3' (2.2 m) in a normal movement (north side down) and a horizontal offset of 20.5' (6.2 m) in a dextral manner (north side to the east). This dip-slip movement is likely a late reactivation of the fault by the same stresses associated with the nearby Tegren cross-fault (A. Lauzon, pers. comm., 1997).

The '04 North break in the 6934 FWD area formed earlier than this late faulting. The earlier '04 break and its related mineralization is the earliest of the structures at this location.

Mapping in this area shows that while the '04 North break sharply cuts the '04 break gold-quartz mineralization, it does not form a knife-like cutting relationship with the '04 break itself. Figure 4.28 shows the shallow dipping '04 North break cutting '04 break gold-quartz mineralization with fault drag consistent with reverse movement on the '04 North break. At other locations, the '04 North break does not always show a sharp cutting relationship with the '04 break. This has been observed on the 6750' (2 057 m)
Figure 4.31. Cross-section looking west, showing the relationships of the various faults in the 6934 area along the line A-B as shown in Figure 4.30.
level in the 6925 RSE and in the 6925 Bench, where earlier mapping by mine geologists shows gold-quartz mineralization of the '04 break truncated by the '04 North break. However, the '04 break appears to continue after the intersection. It is likely that late reactivation along the '04 break has smeared the contact between the two faults preserving only the late reactivation movement recognised as the '04 break.

"Q" Break

The "Q" break is a late cross-fault located in the east end of the Macassa mine workings, approximately 4500' (1372 m) east of the number three shaft near section 5E to 10E. It is of the same generation as the Tegren fault. The fault strikes near north-south and dips from 60-80° east. The fault offsets the '04 break near 5' (1.5 m) in a sinistral direction (west side south). The vertical component is not clear, but there appears to have been minor normal movement (east side down) (Kinross Gold Corp., Internal Report, 1996).

Tegren Fault

The Tegren cross-fault is a major post-ore fault that has been traced in mapping from surface down to the 7050' (2149 m) level, and in diamond drill holes at even greater depths. The fault strikes near 010° to 030°, with the strike rotating slightly to the east at depth. The fault dips steeply to the east, between 75 to 85°, with a gradual steepening with depth. The fault has been observed on surface and on all levels of the mine, where it is located approximately 1900' (579 m) east of the number 3 shaft on the 4250' (1295 m) level and 500' (152 m) east of the shaft on the 7050' (2149 m) level.

The Tegren fault appears as a 1 to 60 cm chloritic seam with characteristic pink carbonate filling and barren quartz. There may be several well defined sub-parallel branches of the Tegren which collectively make up the Tegren cross-fault system. The fault is clearly post-ore. The fault offsets both the '04 break and related mineralization and various hangingwall quartz veins. Figure 4.32 shows the Tegren fault, with characteristic pink carbonate filling, cross-cutting a mineralised section of the '04 break.

Horizontal offset along the fault ranges between 100' to 200' (30 to 60 m) in a
Figure 4.32. View of the Tegren cross-fault from the backs of the 6934 FWD (image has been inverted to give a true plan view). The sub-vertical Tegren cross-fault characteristically appears as a 1-5 cm wide chlorite - pink carbonate filled fault. The post-ore Tegren fault is shown transecting the '04 break and quartz veining. The veining and '04 break are offset some 60 m with the west side up. Rock bolt plates are 12.5 cm across.
sinistral direction (west side south) which has been measured at various levels in the mine on the '04 break. Vertical offset is near 200' (60 m) with the west side up. Vertical offset has been determined using various hangingwall veins (i.e. 4719.37 and 4524.37) and high-grade mineralised zones along the '04 break.

Although the Tegren fault is not mineralised, there are segments along the fault, between offset zones of the '04 break, which contain ripped up zones of quartz fragments. This mineralization is related to the '04 break and contains only locally high gold values. The zones are erratic and narrow making them unimportant for economic mining. Mapping of the 4523 raise by M. Sutton revealed ground quartz fragments from the '04 break zone in the Tegren fault plane, more than 50' (15 m) from the '04 break. Some of the quartz fragments were grapefruit-sized with chlorite-coated rounded edges which assayed >1.00 oz/t gold in selected grab samples.

**Amikougami Creek Fault**

The Amikougami Creek fault is a regional post-ore cross fault similar to the Tegren fault. It can easily be traced on surface in aerial photos and also at various levels underground to the 7050' (2 149 m) level at Macassa. It is approximately 3000' (914 m) west of the Tegren fault. The fault strikes near 345° and dips sub-vertically from 75°E to 85°W. The fault is located approximately 1000' (300 m) west of the number 3 shaft at surface, where the surface expression is represented by the Amikougami Creek.

Development at various levels at Macassa continued to the west on the '04 break until reaching the Amikougami Creek fault on the 4250', 5025', 5300', 5450', 5725', 5875', 6450', and 7050' (2 149 m) levels. On the 4750' (1 448 m) level, development continued to the south along the strike of the Amikougami Creek fault then to the west along the offset portion of the '04 break for another 1400' (427 m) along strike. This development west of the Amikougami Creek fault, on Franco-Nevada property, was completed as part of an exploration joint venture. No significant mineralization was encountered on the '04 break west of the Amikougami Creek fault during drifting. Diamond drilling west of the Amikougami Creek fault had very limited success, and no ore-grade material has been encountered. Hole 57-284 (drilled from the 5725' (1 745 m)
level) drilled at -10° had visible gold reported in silicified quartz stringers associated with the '04 break. This intercept assayed 0.12 oz/t over 1.0'. Hole 64-257 drilled at +10° intersected a zone which assayed 0.14 oz/t over a 5.0' horizontal mining width associated with the '04 break. All other underground drill holes failed to encounter any significant mineralization associated with the '04 break.

In underground exposures, the Amikougami Creek fault is a major fault zone consisting of many sub-parallel branches and splays with combined widths up to 200' (60 m). Within the fault zone, there are a series of well defined, 1 cm to 60 cm wide, chlorite faults with 1 or 2 central or main branches that collectively are up to 1.5 m wide. The fault zone frequently contains characteristic diabase dykes injected along the fault plane. The fault(s) may also contain white and pink carbonate filled zones, and strong brecciated zones containing unaltered angular fragments of adjacent wallrock.

The Amikougami Creek fault offsets all lithologies and the '04 break zone. Individual faults within the fault zone display minor apparent horizontal offset usually less than 1.5 m. Collectively the apparent horizontal offset observed on the '04 break is between 388' (118 m) on the 4750' (1448m) level and 420' (128 m) on the 6450' level in a sinistral direction (west side south). This calculation assumes that the fault labelled as the '04 break west of the Amikougami Creek fault is actually the '04 break. (Figure 2.4 shows the Main break offset by the Amikougami Creek fault. This Figure is based on regional surface geology, and the '04 break shows the same fault offset). Fault drag observed by the author adjacent to the fault zone is consistent with this sense of displacement.

Prior to underground development on the fault, Thomson (1950) calculated horizontal offset on the Amikougami Creek fault to be 900' (274 m) west side south (sinistral). Lackey (1990) calculated the apparent horizontal movement to be 1030' (314 m) (resolved horizontal movement 968' (295 m)) also in a sinistral direction using a mass of basic syenite and pre-fault diabase dykes. The apparent discrepancy in horizontal offset between the earlier works of Thomson (1950), and Lackey (1990), and the current mine workings (average offset 350-450' (~120 m)) may be related to the fact that the earlier measurements are on surface, and the fault may have a rotational sense of displacement.
However, there is also the possibility that the fault labelled as the '04 break west of the Amikougami Creek fault is not in fact the '04 break, but rather a sub-parallel fault that is approximately 600' (183 m) north of the '04 break. The possibility that the break west of the Amikougami Creek fault is in fact not the '04 break has enormous exploration implications.

Vertical offset on the Amikougami Creek Fault is more difficult to determine and also more controversial. Lackey (1990) was the first to seriously consider vertical offset and concluded that the west, footwall side moved down with a dip-slip component of 2650' (808 m)(reverse displacement). This offset was based on the recognition of "discrete stratigraphic markers within the tuff horizons on both sides of the Amikougami Creek fault." This seemingly large offset is questionable for several reasons. Firstly, the same tuff markers may not have been used on either side of the fault. There are multiple tuff units that are not conclusively distinguishable. Secondly, a reverse sense of displacement seems unusual since the somewhat similar Tegren cross-fault (also a sub-vertical, similar strike, cross-fault) has a normal displacement of near 200' (60 m). Lastly, striae reported on the Amikougami Creek fault plane by Watson (1984), on the 5725' (1 745 m) level, plunge 10° north. These sub-horizontal fault-plane slickenlines were also observed by the author to plunge 06° north on the 5725' (1 745 m) level and the 4750' (1 448m) level. A second weaker lineation plunges to the north at 44°. While several generations of movement occurred along the fault, the most recent movement, based upon these striae, appears to have been sub-horizontal to shallowly dipping to the north. This is not consistent with a largely vertical displacement.

Lackey (1990) observed the "northerly drag of both the tuff stratigraphy and its corresponding magnetic trends on the east side of the Amikougami Creek fault." This suggests a dextral strike-slip component. As the '04 break does not show any evidence of dextral movement, there may have been dextral movement on the Amikougami Creek fault in Timiskaming sediments prior to development of the '04 break and mineralization. If the fault was active prior to emplacement of '04 break related mineralization, the fault may have acted as a barrier restricting mineralization to the east of the fault. This may be one of the reasons why no ore mineralization has yet been found west of the Amikougami
Creek fault associated with the '04 break.
Chapter Five
Gold Distribution in Kirkland Lake

Kirkland Lake Gold Production

With the extensive mining history of Kirkland Lake, an analysis of past production is an important element in defining gold distribution. Production records for the seven major past producing mines of Kirkland Lake reveal that, with a total production of 8.5 million ounces of gold, the Lake Shore mine was easily the largest mine in Kirkland Lake (Table 2.2). The Wright-Hargreaves, Teck Hughes, and Macassa mines with 4.8 million, 3.7 million and 3.5 million ounces of gold production, respectively, fall into the mid-tier of producers. The Sylvanite, Kirkland Lake Gold and Toburn mines with 1.7 million, 1.2 million, and 0.6 million ounces of gold production respectively, can be classified as the smaller gold producers within the Kirkland Lake camp.

The production statistics also reveal that the greatest concentration of gold was centred around the Lake Shore mine and decreased outward to the flanking Wright-Hargreaves and Teck Hughes mines (Figure 5.1). These three central mines collectively produced approximately 70% of the total ounces in the camp from a strike length approximately only 35% of the total productive camp-wide strike. Production decreased further west towards Kirkland Lake Gold and similarly moving to the east through the Sylvanite and Toburn mines. The exception is the Macassa mine on the western edge of the camp. This anomaly is largely due to the mine having a much lengthier production history than any of the other mines in Kirkland Lake (Table 2.2), and also having a much larger mineralised strike length (Figure 5.1).

The historical calculated head grades for the seven mines of the camp are shown in Table 2.2. Lake Shore mine had the highest calculated head grade of 0.51 oz/t followed by Wright-Hargreaves at 0.49 oz/t, Macassa at 0.45 oz/t, and Teck Hughes at 0.38 oz/t rounding out the four biggest producers. Records from Teck-Hughes indicate that over the last several years of production, a significant amount of lower grade “slough ore” was milled bringing down the overall average head grade. The smaller mines of Kirkland Lake also generally had lower grades with Sylvanite, Kirkland Lake Gold and Toburn.
KIRKLAND LAKE GOLD PRODUCTION

MACASSA
3,540,601
ozs

KIRKLAND MINERALS
1,172,955
ozs

TECK-HUGHES
3,688,664
ozs

LAKE SHORE
8,499,199
ozs

WRIGHT-HARGREAVES
4,817,680
ozs

SYLVANITE
1,667,520
ozs

TOBURN
570,659
ozs

No. 3 SHAFT
No. 2 SHAFT
No. 1 SHAFT
ELLIS SHAFT
No. 2
No. 1
SOUTH SHAFT
No. 3 SHAFT
No. 2 SHAFT
No. 5 SHAFT
No. 3 SHAFT
No. 4 SHAFT
No. 2 SHAFT

3500' L

3000' L

4500' L

5000' L

7500' L

Figure 5.1. Schematic longitudinal view of the Kirkland Lake camp looking to the north on the ‘04 break / Main break plane. Each symbolic bar of gold represents 100,000 ounces mined.
having average calculated head grades of 0.33, 0.37, and 0.48 oz/t respectively. Toburn had an anomalous head grade that can likely be explained by a modest annual production rate of near 15,000 ounces. This compares to annual production rates at Sylvanite and Kirkland Lake Gold of approximately 48,000 and 28,000 ounces respectively. At such a reduced rate, selectivity of high-grade ore was undoubtedly important.

The comparison of total gold production and historical calculated head grade ignores several important factors. One of the most important factors is total property area of the individual mines. This is particularly important as the seven mines of Kirkland Lake were separated by man-made property boundaries, but were essentially all mining the same ore body associated with the Kirkland Lake break. The author believes that to determine a more unbiased distribution of gold, one should relate the total productive mining area to total ounces produced for each mine in the camp. The results of this comparison are shown in Table 5.1.

The productive mining area is estimated by determining the strike length and vertical depth of areas with extensive mining as demonstrated on long sections showing stoped areas. This method has a built-in bias to favour areas where multiple sub-parallel structures can be mined over the similar vertical and horizontal dimensions. Such a bias is acceptable, as this is an important component of determining the ounces or tonnes of ore per vertical foot commonly used in determining the value of a mine or ore body. Where portions of a mine had significant gaps in extensively mined areas due to factors such as fault gaps or boundary pillars, the areas where little or no mining occurred were not included as productive mining areas (such as the fault gap at the bottom portions of the Lake Shore and Wright-Hargreaves mines).

To calculate a comparable value for the relative gold concentrations of the mines, the total productive mining area in millions of square feet was divided by total gold production (expressed in millions of ounces of gold). This generates a quotient that expresses ounces of gold per unit area. In a simplified sense, the higher the value the greater the concentration of mined gold per unit area. The results in Table 5.1 clearly demonstrate that the Lake Shore and Teck-Hughes mines each with values of 0.45 million ounces of gold per million square feet were the richest mines of the Kirkland Lake camp.
## Gold Distribution In Kirkland Lake Mines

<table>
<thead>
<tr>
<th>Mine</th>
<th>Productive Mining Area (Strike x Depth in Feet)</th>
<th>Total Area (A) (Millions of Square Feet)</th>
<th>Production (B) (Millions of Ounces)*</th>
<th>Ounces of Gold Per Unit Area (B/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Shore</td>
<td>upper central portion 2900' x 5600'</td>
<td>18.9</td>
<td>8.50</td>
<td>0.45</td>
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<td></td>
<td>lower east to 6325'</td>
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<tr>
<td></td>
<td>1500' x 750'</td>
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<tr>
<td></td>
<td>lower main to 8075' level 2000' x 750'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teck-Hughes</td>
<td>1400' x 5800'</td>
<td>8.12</td>
<td>3.69</td>
<td>0.45</td>
</tr>
<tr>
<td>Wright-Hargreaves</td>
<td>upper central to 5100' level 3200' x 5100'</td>
<td>17.8</td>
<td>4.82</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>lower portion west of #5 winze to 8100' level 1000' x 1500'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toburn</td>
<td>1000' x 2500'</td>
<td>2.5</td>
<td>0.57</td>
<td>0.23</td>
</tr>
<tr>
<td>Sylvanite</td>
<td>1700' x 5000'</td>
<td>8.5</td>
<td>1.67</td>
<td>0.20</td>
</tr>
<tr>
<td>Macassa</td>
<td>9000' x 2500' (true average thickness based on plunge to west)</td>
<td>22.5</td>
<td>3.54</td>
<td>0.16</td>
</tr>
<tr>
<td>Kirkland Minerals</td>
<td>1500' x 5850'</td>
<td>8.8</td>
<td>1.17</td>
<td>0.13</td>
</tr>
</tbody>
</table>

* Production ounces are from Table 2.2

# Areas are estimated from the camp longitudinal view and from mine plans in the Thomson (1950) and Charlewood (1964) reports. Strike lengths are based on approximate averages due to irregular boundary pillars.

Table 5.1. Gold distribution within the gold mines of Kirkland Lake.
All of the other mines in the camp had concentrations of gold that ranged from approximately one half to one quarter the concentration of gold at Lake Shore and Teck-Hughes. To help with a visual estimation, one million square feet is equal to approximately 0.093 km$^2$, or roughly the area of ten football fields.

This empirical calculation of gold distribution, combined with total gold production and historical head grade statistics, demonstrates unequivocally that the Lake Shore mine was situated near the centre of the gold-bearing system mined in Kirkland Lake.

**Characteristics of Kirkland Lake Ore**

Characteristics of the ore at Macassa and the other mines of Kirkland Lake are important tools for discussing gold distribution within the Kirkland Lake camp.

**Telluride Minerals**

One of the characteristic components of the Kirkland Lake ore is the presence of a number of different telluride minerals as listed in Table 3.2. The presence of telluride minerals within gold ore occurs at several other well known gold mining areas throughout the world, including Cripple Creek, Colorado (Thompson et al., 1985); the Emperor Mine, Fiji (Eaton and Setterfield, 1993); the Porgera Mine, Papua New Guinea (Richards and Kerrich, 1993); and Kalgoorlie, Western Australia (Boyle, 1979). All of these deposits are Tertiary except for Kalgoorlie which is Archaean.

Invariably the tellurides in gold-quartz deposits are formed late in the depositional sequence (Boyle, 1979). The gold tellurides, chiefly calaverite (Au Te$_2$), and petzite (\((\text{Ag},\text{Au})_3\text{Te}\)) at Kirkland Lake, along with native gold, are often deposited together and after the base metal tellurides in most deposits (Boyle, 1979).

Of the telluride minerals in Kirkland Lake, the most common (listed in relative abundance of occurrence) are altaite (PbTe), calaverite, and coloradoite (HgTe) (Todd, 1928; Hawley, 1950). Of these, the author has noted, on a hand specimen-scale and through polished thin section work, the common occurrence of fine-grained altaite and calaverite with native gold in high-grade ores throughout the Macassa mine. Polished
section work by the author of high-grade ore from the S1 vein from the 4250’ (1 295 m) level revealed the presence of tellurides with roughly the same abundance as reported by Todd (1928) and Hawley (1950). Altaite was the most observed telluride and commonly occurred surrounding a central core of native gold. Calaverite was observed to be frequently intergrown with altaite grains and occasionally small grains of coloradoite and petzite were observed. Altaite was the only telluride mineral that was observed in grains without the presence of other tellurides or gold. Invariably, the other telluride minerals occurred with altaite, gold, and occasionally other tellurides.

The work by Todd (1928) suggested a somewhat systematic increase in the amount of precious metal tellurides (namely calaverite and petzite) along with coloradoite moving to the east from the Kirkland Minerals mine to the Toburn mine. Locations of telluride veins or seams with exceptional thickness were reported at the Lake Shore mine. Some notable examples from the Lake Shore mine included a calaverite seam, up to \( \frac{1}{2}'' \) (1.3 cm) thick, from the No. 801 west stope on the North (No. 2) vein, just above the 800' (244 m) level. Coloradoite was also reported in a seam up to \( \frac{1}{2}'' \) (1.3 cm) thick from the No. 1,019 stope on the North (No. 2) vein just above the 1000' (305 m) level. In most circumstances the North (No. 2) vein had greater concentrations of tellurides than the South (No.1) vein.

Within the Kirkland Lake mines there appears to be little evidence to suggest that there is any significant zonation or pattern to the distribution of telluride minerals with respect to depth. The examples above list telluride associated gold deposits throughout the world that formed under a varying range of temperature and pressure conditions. There is little reason to believe that the differences in character or distribution of the tellurides in Kirkland Lake can be definitively explained on the basis of changes in temperature or pressure of formation.

**Molybdenum**

Molybdenite is the only common molybdenum-bearing mineral associated with gold ore at Kirkland Lake. Molybdenite most commonly occurs along fine slips or minor faults on the margins of auriferous quartz veins. Slickensides have been observed along
the molybdenite coated fault surfaces, indicative of minor localised movement. Molybdenite is generally not intergrown within the quartz, although fragments of porphyry within the quartz may have molybdenum along the fragment margins, suggesting that molybdenum may be an early mineral. The highest concentrations of molybdenite are usually found within some of the highest grade ore at Macassa. There appears to be declining molybdenum content at depth, but this is a general observation by the author, and has not been quantitatively established.

Geochemical analyses from 22 samples of bulk ore from the Wright-Hargreaves mine at 500' (152 m) vertical intervals on both the North and South veins yielded molybdenum values ranging from 0.018 to 0.06 per cent. There was no difference in molybdenite content between the two veins, nor was there any depth relationship established (Thomson, 1950). Analyses of the ore from the Lake Shore mine produced molybdenum values ranging from trace to 0.14 per cent (Thomson, 1950). The data illustrate that the North vein has higher molybdenum content than the South vein (similar to the telluride content relationship), and that there is a positive correlation between high-grade ore and higher molybdenum concentrations.

**Summary of Principal Geological Events**

The '04 break and related sub-parallel breaks and faults, including the Kirkland Lake Main break, were present as normal or strike-slip faults during formation of the Kirkland Lake basin and deposition of Timiskaming sediments (Cameron, 1990). These faults represented major zones of structural weakness and were present prior to the intrusion of elongate alkaline stocks sub-parallel to the strike of the faults. Gold mineralization occurred in the late stages of the intrusive event. During this period, gold-bearing hydrothermal fluid was violently and explosively injected along pre-existing fault structures. The mineralization was focused along the pre-existing fault structures.

All of the studies dealing with offset along the '04 or Main break structures have recognised an overall net thrust displacement which is rotational and greatest to the west (see table 4.1). The main discrepancy has been whether the net thrust offset along the breaks was pre-ore (i.e. Thomson et al., 1950; Charlewood, 1964; McGregor, 1996;
Watson, 1984) or post-ore (Kinross, 1996; Lackey, 1990). Based on observations presented in this thesis, the author believes that the main phase of reverse faulting post-dated the major period of mineralization. Evidence for this includes, late faulting and mylonite development overprinting existing mineralised material in the break zones (Figure 4.6); hangingwall and footwall veins displaced by major break structures; and the main zone of mineralization along the '04 break divided into hangingwall and footwall zones, in the upper and lower portions of the Macassa mine, respectively, by late movement along the '04 break (Figure 4.1).

Summary of the Principal Geological Events


2. *Basin formation*. Deposition of Timiskaming sediments and volcanics in a strike-slip environment during basin formation. A regional strike-slip fault (Kirkland Lake-Larder Lake break) with sinistral movement created narrow deep basins during extension along bends in the fault.

3. *Intrusion of alkaline intrusives*. Intrusion of alkaline magmas from partial melting in the mantle during lithospheric extension. The magma channelled along planes of weakness or faults related to earlier basin formation. The syenite intrusions were injected at slightly steeper angles than the dip of the sedimentary units, cutting the bedding in various places. Three main phases of intrusives were intruded in the following order: augite or basic syenite, felsic syenite, and syenite porphyry.

4. *Cooling of the intrusives*. Cooling of the alkaline intrusions under continued extensional forces created internal stresses during contraction which created sets of joints, fractures, and possibly faults (Thomson, 1950). A major fault system developed along this plane of weakness with a braided network of faults occurring throughout the stocks, sub-parallel to the long axis.
5. **Hydrothermal activity.** During syenite emplacement and cooling, a prolonged period of hydrothermal activity resulted in hydrothermal injection along planes of weakness and fracture systems located primarily in the syenite intrusions. This hydrothermal activity was genetically linked to the emplacement of the syenitic stocks.

6. **Mineralising period.** Quartz veining and gold mineralization was deposited in repeated cycles of hydrothermal fracturing and brecciation and in open space filling of existing structures. The centre of this hydrothermal system was based near the central core of the Kirkland Lake camp, namely the Lake Shore mine and the neighbouring Teck-Hughes and Wright-Hargreaves mines. Veining was concentrated in a stockwork pattern in and around the syenite porphyry near this central portion of the camp along the main plane of faulting. Towards the east end of the camp, the fluids migrated along multiple pre-existing fractures and fault planes that acted to disperse and dilute the localised mineralization. Towards the west end of the camp, mineralising hydrothermal fluids concentrated along the main plane of weakness that transferred from the Main break to the '04 break on the Macassa property with local blowouts along existing faults and fractures. The western extent of the known mineralised zone occurs beneath the 7050' (2 149 m) level at Macassa and remains open at depth.

7. **Compressional stage late in the ore-forming period.** During the final pulses of gold-rich hydrothermal activity, a compressional regime began which deformed the existing mineralised zones. The most notable and recognisable feature of this period of deformation was the re-activation of earlier normal faults as steep reverse faults. Steep normal faults that previously acted as conduits for hydrothermal fluids were overprinted by major reverse faults and breaks with the characteristics of the main faults and breaks as can be seen along the '04 break and the Main break. Compression also created a new set of flatter-dipping thrust faults including the −50° S dipping No. 6 break that has been mapped across much of the western and central portions of the camp. Fractured rock between the breaks provided an excellent conduit to form a series of ore-bearing quartz veins (hangingwall veins), that included veins along
steeply dipping shear zones and flat tension veins. The later thrust faults, such as the No. 6 break, are not as extensively mineralised as the major sub-vertical breaks of the camp suggesting that they may represent a weaker period of mineralization and/or they acted as conduits to remobilize gold from the adjacent mineralised structures.

8. **Post-ore compressional deformation.** Prolonged stages of compression are marked by a later series of non-mineralised flat thrust faults. These faults include the ~30° south dipping '04 North break at Macassa and the flat to gently north dipping Nos. 1, 2, 5, and 6 faults to the east at the Wright-Hargreaves mine. These thrust faults are generally sub-parallel to the strike of the earlier mineralised breaks and may cause displacement of the mineralised zones by hundreds of feet. They will usually cause a sharp knife-like intersection along mineralised veins that do not occur along a major structure, and may cause significant fault drag of mineralised break structures at their intersection.

9. **Post-ore cross-faulting.** Development of major sub-vertical cross-faults such as the Tegren and Amikougami Creek faults at Macassa generally strike to the north at high angles of intersection with the break zones. Displacement along these faults can be in the order of hundreds of feet. Scattered zones of barren quartz-calcite veining are present along these faults. Diabase dykes (Matachewan swarm) may occur along these planes of weakness as is evident along much of the plane of the Amikougami Creek fault at the extreme west end of the Kirkland Lake camp.
Chapter Six
Exploration at the Macassa Mine

"The fact that the ore zone at Kirkland Lake does not always lie along the plane or zone of maximum displacement (Main break) has been amply demonstrated in the history of the camp, especially at the east end, and at depth in such mines as Kirkland Lake Gold. This should encourage a greater exploration across and along the entire intrusive stock and adjacent sediments and tuffs. The distant future of the camp will depend to a considerable extent on the success of this lateral exploration."

Thomson, 1950

The above observation made by James Thomson more than 50 years ago is certainly still valid today. Future exploration efforts at the Macassa mine must focus on discovering additional mineralization that is outside the main mineralised plane along the '04 break and the Main break. Gold remains to be discovered along the '04 break along suspected plunges and shoots both up and down-dip, but additional structures that have the potential to contain significant ounces of gold on a mine- or camp-wide scale remain as substantial targets. This chapter will summarise the geological criteria for hosting ore zones, and then discuss several key exploration targets specific to the Macassa mine.

Characteristics of Mineralised Material

1) Camp-wide ore-bearing structures: The importance of the Main break (Kirkland Lake break) and the '04 break cannot be stressed enough. These main structures have hosted the vast majority of ore in the Kirkland Lake camp.

2) Major structures: Lesser important structures such as the '05 break (Narrows break) and the No. 6 break, can host significant mineralization, but are generally less prospective than the major structures. Some of the structures exist on a camp-wide scale and are generally under-explored targets.
3) **Host rocks:** Thomson (1950) estimated that approximately 95% of the ore mined in the Kirkland Lake camp came from veins located within or along the contact of the intrusive rocks. Approximately two thirds of the ore was from syenite porphyry and one quarter from intermingled augite syenite, syenite, and syenite porphyry. Ore located in the sediments makes up a much smaller amount, and stoping within these units was generally narrower than in the intrusives. The longest ore shoot within the Kirkland Lake camp is located within an area of syenite porphyry. The area was almost completely mined for approximately 2 km along strike near the 3,000’ (915 m) horizon across the Teck-Hughes, Lake Shore, and Wright-Hargreaves mines on the No. 3 and North veins respectively. At the west end of the camp, at the Macassa Mine, augite (basic) syenite is the most common ore host rock with lesser amounts of ore occurring within and adjacent to syenite porphyry, felsic syenite (syenite), tuff, and conglomerate. The latest and best-mineralised component of the differentiated syenitic units was syenite porphyry. This preferential gold enrichment may be directly related to the timing of gold and telluride deposition late in the mineralization process.

4) **Structurally complex areas:** Most gold from the Kirkland Lake camp comes from ore adjacent to the Kirkland Lake fault system. However, the more complex the localised faulting, the greater the likelihood of richer and more extensive ore. Branches or splays of major structures form anastomosing lenses of rock that can either be in the form of massive mineralised zones, bounded by two structures, or as areas of numerous quartz vein systems with a variety of different orientations. The highly faulted areas of ground between major faults, such as between the '04 break and Main break at the east end of the Macassa Mine, is one such example of an excellent location for multiple ore-bearing quartz veins of varying orientations over widths of approximately 800 feet (250 m). Sub-parallel breaks are excellent locations for pockets of wide ore (breccia ore) between the two structures (i.e. as discussed in Chapter Four between the '04 break and the South break at Macassa).
5) **Plunges or “Shoots” of ore:** The use of longitudinal sections to visually represent ore-grade material is an invaluable tool to project ore beyond known limits. This is particularly evident in the general camp wide trend to the west of 30° (Figure 2.6). However, this relationship must be used with caution as the camp-wide projection is roughly based on the overall orientation of the suite of syenitic intrusives and mining on the Kirkland Lake break. The camp-plunge does illustrate the importance of localised plunges. At the west end of the Macassa mine most of the mineralization is hosted by the ‘04 break and associated with augite syenite, while at other parts of the camp most of the mineralization is hosted by the Main break associated with syenite porphyry.

It is also important to note that although structures may have many similar characteristics they can have completely different plunges. For example, the short, steeply-plunging west ore shoots of the ‘05 break at Macassa (Figure 4.1) are different than the main ore shoots of the ‘04 break (Figures 6.1 and 6.2).

6) **Alteration Packages:** As a general rule, the ore-bearing portions of major structures in the Macassa Mine have more extensive bleaching and alteration than poorly mineralised zones. These ore-bearing areas will generally have chlorite-sericite-carbonate-hematite alteration with buff to red-brown altered rocks for several meters peripheral to the major structures. A recent exploration diamond drill hole drilled in 1999 near the 2,400’ elevation (732 m) at Macassa intersected the ‘04 break in conglomerate that contained no significant mineralization. The break was a thin chlorite-healed fault zone, less than 1 cm wide, with very weak carbonate alteration of the host conglomerate. The zone was so poorly developed that if it were to occur in an area that was not near the target, it would be described as a minor or even insignificant structure.

7) **Cross-fault structures:** Major cross-faults in the Kirkland Lake camp such as the Lake Shore fault and the Tegren cross-fault all show post-ore net displacement (Figure 2.8 and 3.2, 3.3 respectively). However, there is also an important observation
that major cross-faults can offset portions of the richest and most extensive ore in the Kirkland Lake camp. The Lake Shore fault (Figure 2.8) near the boundary of the Lake Shore and Wright-Hargreaves mines displaces some of the highest-grade ore in the Kirkland Lake camp approximately 100' (30 m) in a sinistral direction (east side north). The sub-parallel Tegren cross-fault occurs within some of the richest '04 break ore at the Macassa Mine and displaces the ore approximately 250' (76 m) also in a sinistral direction (east side north). These and other sub-parallel structures may indeed have played a role in the mineralising environment only to be reactivated during post-ore compressional regimes.

The Amikougami Creek cross-fault at the west end of the Macassa property (Figure 2.4, 3.3) appears similar to cross-faults located within rich ore zones. However, there are two major features that make this fault different than other cross-faults within rich ores. This fault has a strike approximately 20° more to the north than these other faults, and it is also associated with a diabase dyke injected along the fault plane. The Amikougami Creek cross-fault appears to act as a boundary to any significant mineralization further to the west in the Kirkland Lake camp. However, the offset along this fault has not been reasonably established, and the area to the west has seen very limited diamond drilling.

8) **Depth relationships**: Mining at the Macassa mine, and indeed throughout the Kirkland Lake camp, has demonstrated that there is no clear relationship with ore and depth. The ore at the deepest levels of the camp can be as rich as ore near surface, and there is no clear mineralogical change in ore at depth.

**Exploration Targets at Macassa**

'04 Break Exploration

As the single most important source of ore in the Macassa mine within the past thirty years, it is important to address the future exploration potential for mineralization related to this structure. With the use of longitudinal views the distribution of ore related
to the '04 break can follow distinct shoots or plunges (Figures 6.1 and 6.2). Extrapolating this onto a mine-wide scale, it is clear that potential to discover new ounces along the '04 break exists up-dip and down-dip from mineralised zones. Up-dip potential is highest along two “high-grade” plunges identified as areas 1 and 2 on Figure 6.1. Area 1 exists above the 4250’ (1 295 m) level above an area where the 4247 reserve block was identified in 1998. This area has the potential to host stope-scale lenses of ore up to twice the average historical head grades with widths typically from 5’ (1.5 m) to 10’ (3.0 m). The size of the 4247 resource block of near 50,000 t at a grade of 0.80 oz/t is typical of mineralization that remains almost entirely untested along this plunge up to surface.

The area labelled 2 on Figure 6.1 follows what can be thought of as a conjugate plunge towards the east. This plunge remained just beyond exploration drifting on the 3800’ Level that was halted in 1999. This plunge also remains largely untested up to surface along the western border with the Tegren cross-fault.

Down-dip potential for mineralization along the '04 break remains sparsely tested below the 7050’ (2 149 m) Level. Although the deposit remains open almost entirely down-dip, the economical and safety considerations of deeper mining must be carefully reviewed before any significant expenditures are made to test for mineralization at depth. Both the Lake Shore and the Wright-Hargreaves mines mined below 8000’ (2 438 m) with mineralization continuing at even greater depths. The ore mined from the 8075’ (2 461 m) Level at Lake Shore was continuous for 807’ (246 m) along strike at a grade of 0.677 oz/t (approximately 33% higher than the average grade over the history of the Lake Shore mine). There is every reason to believe that the same depth potential exists at the Macassa mine. The plunges identified on Figure 6.1 as 3 and 4 remain excellent targets to further delineate some sparsely drilled pre-existing resources below 7050’ (2 149 m) Level.

The area identified as 5 on Figure 6.1 is mineralization that exists below the '04 North break at depth. This area may follow a similar trend to depth as the area identified just to the west as 4. Even further to east than shown in Figure 5.3, excellent exploration potential exists also beneath the '04 North break, where the offset is increasing towards the east (as demonstrated in Figures 4.25 and 4.26).
Figure 6.1. Grade contours at the Macassa mine along the ‘04 break, projected onto a longitudinal section looking 32°30’ west of north. The area below the ‘04 North fault gap is sparsely drilled but has several resource blocks identified with grades up to 1.00 oz/t.
Figure 6.2. Contours of horizontal widths of mineralized material (>0.25 oz/t) at the Macassa mine along the '04 break, projected onto a longitudinal section looking 32°30' west of north. The area below the '04 North fault gap is sparsely drilled.
When considering the exploration potential along '04 break-related ore plunges at Macassa, it is important to consider why the plunges exist. The high-grade ore plunges illustrated in Figure 6.1 are largely related to structural and lithological controls. Most of the ore is hosted within intrusive units, chiefly augite syenite. The camp-wide plunge to the west, as illustrated in Figure 2.6, is largely related to the plunging intrusive units. There are units of augite syenite above this plunge at the upper levels at Macassa and locations of these units are an important ingredient for ore formation.

Ore is frequently controlled by the plunging intersection lines of two faults – most commonly the '04 break and a branching or splay fault. The intersection of two of these plunges may cause an even greater concentration of high-grade material as is identified by the apparent blow-out of high-grade ore at the converging limbs of an apparent "V" structure (Figure 6.1). This area of high-grade and wide ore was known as the "Lower Main" at Macassa. The area was extensively developed and was the location of major longhole stoping blocks at the time of the major rockburst of 1997 that damaged the main production shaft (No. 3 Shaft).

The ore thickness plot of Figure 6.2 generally mimics the high-grade trends throughout Macassa. It was this excellent combination of high-grades and locally great widths that made Macassa a 3.5 million ounce gold producer. All of the wide areas of ore at Macassa are structurally controlled. Areas of breccia ore in access of 50' wide (15 m) form between sub-parallel structures with distinct plunges along their lines of intersection. Recognising these plunges with the use of longitudinal sections is an invaluable tool to explore for and develop areas of wide ore. Initial diamond drilling above the 3800' (1 158 m) Level indicates the presence of two structures with localised zones of ore-grade mineralization extending between the two sub-parallel structures. Further exploration work should be conducted in this area in conjunction with the projection of high-grade mineralised plunges as shown in Figure 6.1.

**Exploration South of the '04 Break**

Of all of the exploration potential at Macassa, the structure with the greatest potential to yield significant ore is the No. 6 break and related sub-parallel structures. The
No. 6 break was discussed in Chapter Four as a camp-wide structure to the south of the '04 break and the Main break, yet the structure has been remarkably under-explored compared to these other structures. Particularly at the west end of the camp, the No. 6 break holds enormous potential to host ore that is similar to '04 break ore in terms of grades, continuity, and extent. At the Kirkland Minerals property a large portion of the mined ore came from the No. 6 break, particularly at depth. Only one stope was mined on the structure (4529.37 stope) at Macass. The strike length between the two mining areas is well in excess of 5000' (1 500 m), and remains almost entirely unexplored. Several drill holes drilled shortly before the mine closed in 1998, yielded spectacular results in holes drilled from the 4750' Level at Macass. Many of the intersections included visible gold and tellurides over widths ranging from 5' (1.5 m) to 12.8' (3.9 m) horizontal mining widths.

In addition to the No. 6 break there appear to be several sub-parallel or branching mineralised structures in the hangingwall of the '04 break. Diamond drilling shortly before the mine closed included intersections of 0.76 oz/t over 12.8' (3.9 m) (HMW) some 400' (122 m) south of the No. 6 break, and 0.48 oz/t over 5.0' (1.5 m) (HMW), on another zone some 100' (30 m) south of the No. 6 break. None of these zones have been developed at Macass, and they are completely open in all directions. These structures are likely similar to No. 5 vein that was an important source of ore at the Kirkland Minerals mine further to the east (Figure 2.11). The No. 5 vein was a 50° south-dipping hangingwall vein structure that branched off the Main Break some 300' (91 m) above the No. 6 break. The vein was mined as a continuous sheet of ore from the 3 475 foot (1 059 m) level to the 3 875 foot (1 181 m) level along a strike length of 1 200 feet (366 m).

The Teck-Hughes mine also processed ore from 50° south-dipping structures branching off the Main break that included the E, F, J, and L veins. These veins were located both above and below the No. 6 break over vertical depths of approximately 5000' (1 500 m). The dip-length projections of ore on ~50° south dipping structures can be extensive. The F vein at Teck-Hughes was mined for over 700' (213 m) down-dip to locations in excess of 1000' (305 m) to the south of the Main break.

Exploration efforts targeting the No. 6 break should clearly also test for sub-
parallel structures dipping near 50° south in both the hangingwall and footwall of the No. 6 break. As with the '04 break, establishing the orientation of mineralised shoots or plunges is important for exploration success. However, it must not be assumed that the trends and plunges are constant across broad areas of one structure or along different structures in similar locations. The shoots of ore on the No. 6 break-related ore at the Kirkland Minerals and Teck Hughes mines have a definite steep easterly plunge, unlike the typical westward-plunge throughout the rest of the Kirkland Minerals property (Charlewood, 1964).

The whole suite of alkaline intrusives south of the Main break and '04 break structures are prospective areas to host mineralization. Exploration should also test as far to the south as possible for new structures and down-dip projections from structures at higher elevations.

**Exploration North of the '04 Break**

Exploration to the north of the Main break and '04 break structures for structures that include the Narrows break is as critical as exploration to the south for structures such as the No. 6 break. Earlier descriptions in Chapter Four identified the '05 break at Macassa as the same structure as the camp-wide Narrows break, therefore this discussion will simply refer to the structure as the Narrows break.

Exploration on the Narrows break should be guided by the same general structural constraints that have perpetuated exploration on the '04 break. Emphasis should be placed on following up on projected plunges of mineralised zones, and in defining structurally complex areas where multiple splays or branches occur with localised blow-outs of wide ore. Several near-surface targets exist on the structure where previous stripping has revealed typical values of 0.20 to 0.25 oz/t over 5-7' (1.5 – 2.1 m) widths. These targets should be evaluated on a priority basis considering the low costs for further short definition holes or further stripping and the potential for surface mining. Longer exploration holes can define loosely evaluated mineralised shoots underground, but consideration should also be given to fully exploring for similar sub-parallel structures further to the north within the suite of prospective tuffs and alkaline intrusives. Such
targets include follow-up work on the BAZ ("brown altered zone") at Lake Shore.

**Hangingwall and Footwall Veins**

Production histories for all of the mines in the Kirkland Lake camp clearly demonstrate the importance of hangingwall veins, and to a lesser extent footwall veins, as alternate sources of ore to '04 or Main break mineralization. This was particularly true in the latter years of the production life of a mine, as the prime sources of ore along the major break structures were depleted. The same was true also at the Macassa mine, where hangingwall veins including the 4719.37 stope provided valuable mill feed that could on a monthly basis total up to approximately one half of all ore.

There is evidence for the structural control of major concentrations of hangingwall veins in zones bounded by two break structures. This occurs at Macassa between the '04 break and the Main break (Kirkland Lake fault north branch) at the east end of the mine (Figure 4.8) and between the '04 break and the No. 6 break in the west and central portions of the mine (schematic cross-section Figure 4.16). Similar relationships also exist to the east of Macassa at the Kirkland Minerals mine between the Main break (Kirkland Lake Fault) and the No. 6 break (Figure 2.11). The intersection between the '04 break and the No. 6 break remains under-explored for mineralised hangingwall veins across almost the entire Kirkland Lake camp.

A more detailed view of the mineralised hangingwall veins between two major faults is shown in Figure 6.3 at the Kirkland Minerals mine and in Figure 6.4 at the Macassa mine. Despite being separated by a distance along strike of approximately 5000' (1 500 m), the two sections show remarkably similar characteristics. Augite syenite is the predominant host rock for both examples. Both sections show a series of primarily vertical to steeply south-dipping mineralised quartz vein that generally change to vertical or steeply north-dipping towards the No. 6 break.

A distinct antiform structure labelled the No. 10 vein at Kirkland Minerals (Figure 6.3) is mimicked by an antiform vein shown on the Macassa section (Figure 6.4). This antiform vein at Macassa was only truly recognised in 1998 or 1999, a short time before the mine was closed. In a schematic sense the projection of the fold hinge line
**Figure 6.3.** Geological cross-section through the Kirkland Minerals mine showing the series of hangingwall veins located between the Kirkland Lake Fault (Main break) and the No.6 break (Charlewood, 1964).
Figure 6.4. Composite cross-section through the Macassa mine at section 26+50 W looking east. The section has been expanded up to 250' in the near direction (west) so that multiple stoping areas can be shown. The '04 break and the No 6 break are the dominant structures, and multiple mineralised hangingwall veins occur between the structures at a variety of different orientations. The mining shown on the 4527.37 vein (antiform) was actually mined from the east end of the 4529.37 stope where the vein rolls flat into the footwall of the 50° dipping No 6 break stope.
between the two structures would be oriented with a flat plunge to the west. This is almost identical to the 10° west plunging line of intersection between the '04 break and the No. 6 break at Macassa as discussed in Chapter Four. There has been very little if any exploration work trying to project antiformal structures from Kirkland Minerals across almost the entire Macassa property, and thus the area remains a highly prospective target.

An understanding of the multiple possible orientations of hangingwall veins is important for successful exploration. Bearing in mind that veins can be sub-horizontal (i.e. 4719.37 complex) to sub-vertical (most common orientation); south to north dipping (i.e. 4526.37 and 4527.37 veins); planar, folded or antiformal; and have a variety of strike orientations, drilling patterns must carefully be considered in geologically favourable conditions. As most drilling has attempted to be on section with flat to moderately inclined holes consideration must be given to drilling sub-vertical holes to test large vertical zones with favourable geological criteria. Holes should also be drilled through geologically favourable locations along the general strike of the ore body (approximately 060degrees) to test for veins with strikes at large oblique angles to the major break structures (such as the north-striking 4218.37 hangingwall vein).

Another key element to exploring for hangingwall or footwall veins must be to consider the post-ore displacement along the major break structures such as the '04 break. As discussed in Chapter Four and as shown in Table 4.1, the net displacement along the '04 break appears to have a rotational reverse displacement that increases from east to west, where the net displacement is up to 1500' (450 m). This may also explain why most break-mineralization is located in the footwall of the break, and why there are greater concentrations of footwall veins at the bottom elevations of the mine (primarily below 5825' Level). However, the upper levels of the mine contains most break-ore in the hangingwall of the break, and there is a much greater concentration of mineralised hangingwall quartz veins with rare footwall veins.

Considering this displacement, it may be possible to test for the up-dip or down-dip extensions of either hangingwall or footwall veins that may have initially formed as continuous mineralization across the break structure. For example, if the footwall veins that were mined in the 5620 stope (T veins) were initially formed along a shear on either
side of the major break structure, then there may be an up-dip component of the vein on
the hangingwall side of the break. Using a net displacement at section 20W of 1360' (415
m) (Wright, 1979), there should be a continuation of the 5620 vein into the hangingwall
of the '04 break near the 4250' (1 295 m) Level. Indeed in this area several localised
hangingwall veins are labelled as the 4218.37 and 4217.37 veins. Detailed mapping
and/or thin section work could be used to establish more concretely that the veins are
indeed the same zone displaced by late movement along the '04 break.

The use of projected displacements for structures across the major break structures
holds vast exploration potential. This is particularly important as either an established
hangingwall or footwall vein can be used to calculate the elevation of a potential up-dip
or down-dip component.
Chapter Seven
Summary and Conclusions

The Macassa mine has a long history of production, and a lot of previous information exists about the major structures of the Kirkland Lake camp. However, there has not been a comprehensive review of the structural geology of the Kirkland Lake gold camp since Charlewood (1964) updated the deep developments of the camp. There has not been a significant review of the geology of the Macassa mine since the work by Lackey (1990). The primary objective of this study was to prepare a compilation of the structural geology of the Macassa gold mine. This information has been used to generate a model for the timing and controls of gold deposition, and to generate new targets for exploration.

'04 Break

Descriptions of the geology of the '04 break have been expanded to include newly gained information through exploration development on the new uppermost level of the mine (3800' or 1158 m). New information has also been gained through diamond drilling beneath the deepest level (7050' or 2149 m). The apparent confusion in nomenclature of the '04 break, between the Upper and Lower beats of the mine (between the 5700' and 5825' levels), has been clarified. The '04 break in the Upper levels of the mine correlates with the structure identified as the North break in the Lower levels of the mine.

Locations for ore-grade sections of the '04 break have been explained through three key criteria: regularly defined shoots or plunges; structurally complex areas; and preferential host rocks. Structural evidence has been presented to demonstrate that the '04 break is a reactivated fault zone with late deformation overprinting earlier penetrative deformation and mineralization.

A series of intermineral felsic green dykes overprint mineralised quartz veins associated with the '04 break. The dykes themselves are also locally mineralised with strong silicification and ubiquitous sulphides. Additional mineralogical research and age-dating is recommended on these structures to determine their composition, and to possibly establish a timing constraint for gold mineralization.
'05 Break

Descriptions of the '05 break have expanded the structural knowledge of this fault zone. Multiple generations of deformation have been identified. The evidence suggests that an earlier mineralised structure was deformed in a compressional regime. Deformation has been preserved in a variety of forms. There is evidence of a mylonite overprinting a crushed chloritic fault zone. Pebbles in conglomerate, located in the footwall of the '05 break, are deformed with the long axis of deformation parallel to the break zone. There are boudinaged ribbons of quartz, and tight folding of quartz veins with the axial plane parallel to the '05 break. Sub-vertical faults locally intersect the mineralised '05 break zone at 45° angles. These faults offset the zone by approximately 1 foot (30 cm) in a dextral manner.

The '05 break zone has been established as the same structure identified as the Narrows break in the eastern portions of the Kirkland Lake camp.

No. 6 Break

The No. 6 break has a very limited mining history at the Macassa mine. New structural descriptions update information from previous reports. The No. 6 break extends from the Macassa mine across most of the other mines in the Kirkland Lake camp. Evidence suggests that the No. 6 break is a reverse fault. Two models for the formation of the No. 6 have been proposed. The No. 6 break may post-date the original formation of the '04 break. In this case, the '04 break would have pre-existed as a steep, likely normal, fault. During a later stage of compression, the No.6 break could have formed as a 50° south-dipping reverse fault intersecting the '04 break and reactivating the upper part. The '04 break appears to flatten in an area that is smeared along the contact with the 50° south-dipping No. 6 break. Alternatively, the No. 6 break may have formed as a flattening or horse-tailing splay near the termination of the '04 break. Subsequent fault movement could have extended the '04 break down to lower levels with the No. 6 break remaining as a discontinuous branch of the '04 break.

Hangingwall Veins

As the supply of '04 break ore diminished at the Macassa mine, the reliance on
hanging wall veins as an important source of ore increased. Most of the significant styles of hanging wall veins have been described and documented. Hanging wall veins are excellent markers to show post-ore deformation. Multiple examples of post-ore folding and faulting have been documented.

'04 North Break

A series of eleven idealised cross-sections of the '04 North break have been constructed to show the displacement of the '04 break between sections 40 West and 5 West (a distance of 3500' or 1067 m). The sections demonstrate that the fault has a scissor-like fault movement, with consistent reverse displacement. Offset of the '04 break increases from 58' (18 m) at 40 West, to 281' (86 m) at 5 West. Such projections hold vast exploration potential at the east end of the Macassa mine, and into the Kirkland Minerals property, where offset of structures by the '04 North break has previously been poorly understood. Zones of mineralization, consisting of silicification and weak quartz veining, have been identified associated with the '04 North break. These zones are sub-economic and appear later than the quartz veining associated with the '04 break.

Amikougami Creek Fault

The Amikougami Creek fault effectively forms the western limit of significant ore in the Kirkland Lake camp. Offset along this fault holds enormous implications for exploration. The apparent offset on the fault, at or near-surface, as measured from the '04 break by previous authors, is between 900' (274 m) and 1,030' (314 m) in a sinistral direction (west side south). Measurements by the author, from underground mapping, reveal an apparent offset between 388' (118 m) and 420' (128 m), also in a sinistral direction. This discrepancy suggests that the fault may have a rotational sense of displacement. Alternatively, the structure identified as the '04 break on surface and in underground exposures may not be the same structure. Assuming that the fault has a consistent offset, then the structure identified as the '04 break west of the Amikougami Creek fault in underground exposures, may not be the '04 break, but rather a similar sub-parallel structure. If this is the case, there may be another structure approximately 600' (183 m) to the south of the structure identified as the '04 break west of the Amikougami
Creek fault in underground exposures.

Vertical offset along the Amikougami Creek fault has not been concretely determined. Evidence collected by the author suggests that the vertical offset is most likely in the range of several hundred feet (~100 m), and not 2650' (808 m) as presented by Lackey (1990).

**Gold Distribution**

The author has utilised several different methods to examine gold distribution in the Kirkland Lake gold camp. This analysis confirms that the Lake Shore mine was situated near the centre of the gold-bearing system mined in Kirkland Lake.

**Summary of Principal Geological Events**

The structural evidence compiled in this thesis suggests that the main phase of reverse faulting post-dated the major period of mineralization. This fits into a sequence of principal geological events that supports earlier work by Kinross (1996) and Lackey (1990). A summary of principal events includes:

1. Early volcanism
2. Basin formation
3. Intrusion of alkaline intrusives
4. Cooling of the intrusives
5. Hydrothermal activity
6. Mineralising period
7. Compressional stage late in the ore-forming period
8. Post-ore compressional deformation
9. Post-ore cross-faulting

**Implications for Exploration**

A series of exploration targets have been developed through the compilation of the structural geology of the Macassa mine. Most of these targets have the potential to contain significant ounces on a mine- or camp-wide scale. Most of the structures themselves are not new, but the structural model can support the focus for their exploration.
'04 Break

Plunges and shoots of ore, identified on the '04 break, challenge the previous belief that all ore plunges steeply to the west throughout the Kirkland Lake camp. This trend exists for the Main break, but two separate ore plunges have been identified on the '04 break. These ore shoots plunge up to the west above to 4247 area, and up to the east around the 4224 area. Mineralization at the Macassa mine remains strong at depth, and the down-dip portion of the '04 break below the 7050' (2149 m) Level remains highly prospective.

South of the '04 Break

The No. 6 break has been established as a highly prospective target south of the '04 break. Mineralization is present along the break zone, in sub-parallel zones in the hangingwall of the break, and in mineralised quartz veins of variable orientations between the No. 6 break and the '04 break. Most of these targets remain sparsely tested for a strike length of approximately 5,000' (1.5 km) eastward to the Kirkland Minerals property.

A correlation has been established between the antiformal structure mined as the No. 10 vein at Kirkland Minerals, and a newly identified antiformal vein at Macassa. This structure, and possible related mineralised veins, also remain sparsely tested for a strike length of approximately 5,000' (1.5 km) to the east.
REFERENCES


