HOST ROCK AND FLUID CONTROL ON CARBONATE ASSEMBLAGES IN THE GOLDEN MILE DOLERITE, KALGOORLIE GOLD DEPOSIT, AUSTRALIA

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ABSTRACT

Four carbonate minerals occur in the differentiated tholeiitic Golden Mile Dolerite sill, Kalgoorlie (Australia), and all are related to carbonation and sulfidation processes that accompanied gold mineralization. Ankerite, the most widespread carbonate, occurs throughout the dolerite and in the zones of chlorite, carbonate and pyrite alteration. Calcite occurs sporadically in the chlorite zone within less-differentiated host rocks. In contrast, siderite is abundant in the carbonate zone and more differentiated sections of the dolerite. Dolomite is found in all parts of the dolerite, but is restricted to the pyrite zone, where it formed from intense sulfidation of ankerite-bearing wallrocks. All compositions from dolomite to ankerite occur in single samples from the pyrite zone, whereas the chlorite and carbonate zones contain uniform mineral compositions. Host-rock composition has a strong control on alteration-mineral assemblages, but exerts only a minor effect on carbonate-phase compositions; instead, the latter mainly reflect the temperature (300-350°C) and composition of the gold-bearing fluid with which they equilibrated. Such a conclusion can be extended to other Archean greenstone lithologies to explain the carbonate species found in ultramafic rocks, metabasalts and formations of fer rubbannées.

Keywords: carbonation, sulfidation, siderite, calcite, dolomite, ankerite, gold mineralization, Archean, Kalgoorlie, Australia.

INTRODUCTION

Carbonate alteration is an important feature of Archean greenstone belts; it is well displayed in komatiite-associated (e.g., Gresham & Loftus Hills 1981) and komatiitic dunite-associated nickel deposits (Donaldson 1981), in metabasaltic sequences (Hallberg 1972) and in epigenetic gold deposits (Kerrick & Fyfe 1981, Groves et al. 1982, 1984, Kerrich 1983, Phillips & Groves 1983). Some major gold deposits are surrounded by a halo of carbonate alteration in excess of 1 km in diameter (Larcombe 1912, Bartram & McCall 1971, Travis et al. 1971, Fryon & Crock et 1982, Davies et al. 1982). The most common carbonate phases in greenstone belts are ankerite, siderite, calcite, dolomite and magnesite; although several carbonates may occur in individual deposits (Bartram 1969), very few investigators have attempted to explain the distribution of different carbonate minerals (e.g., Kerrich & Fyfe 1981). Fluid-inclusion data, including those for Kalgoorlie (Ho et al. 1985), give no indication of highly variable values of the H2O/CO2 ratio or variations in CO2 activity that may account for the different carbonate minerals.

The identification of four carbonate minerals within the Golden Mile dolerite sill at Kalgoorlie provides an ideal opportunity to study carbonate distribution within a limited and geologically constrained environment (Phillips 1985, 1986). This study demonstrates the importance of host-rock control within the halo of carbonate alteration and of...
sulfidation reactions within the gold lodes. Pairs of coexisting carbonates also constrain temperature during alteration. The model developed for the Golden Mile Dolerite can readily be applied to other greenstone lithologies, or to the same lithology elsewhere.

In the Golden Mile Dolerite and some other greenstone-related gold deposits, major elements such as Al, Ti, Fe, Mg, Ca and Na are relatively immobile during gold mineralization, except in the most intensely altered areas such as shear zones (Phillips 1985, 1986). The significance of this immobility was recognized by Kerrich & Fyfe (1981) and Phillips & Groves (1984), who showed that the levels of major elements were not substantially changed during alteration and, therefore, major lithological variations correspond to changes in carbonate assemblages. The present study extends their conclusions to illustrate how the proportions of Fe, Mg and Ca in the host rocks exert an important control on the type and composition of the carbonate minerals.

The Golden Mile Dolerite has been subdivided into ten mappable units, of which Units 7, 8 and 9 represent 80% of the sill. Four sections typify the major compositions within the sill (Table I, Fig. 1), and have been used for detailed sampling of these three units.

GEOLOGICAL SETTING OF THE GOLDEN MILE DOLERITE

The Kalgoorlie district is situated within the Norseman-Wiluna belt of the Archean Yilgarn Block, Western Australia (Groves & Batt 1984), and has been a major source of gold (12@ tonnes Au recovered). The main host-rock, the Golden Mile Dolerite, is a 4C0- to 6@-m thick, differentiated tholeiitic sill intruded between underlying mafic and ultramafic rocks (Fig. 1), and overlying metasediments and felsic metavolcanic units (Travis et al. 1971). South of Kalgoorlie, the dolerite has been subdivided into ten mappable units (Iravis et al. 1971), and recently this subdivision has been extended by mapping of the underground workings in the Golden Mile, Kalgoorlie (Phillips 1986).

The marginal units of the Golden Mile Dolerite (Units 1 and 10) are fine-grained; their composition approximates that of the whole sill. The interior units of the dolerite vary from a more Mg-rich pyroxene-phyric phase at the base and top (Units 2, 3, 4 and part of 9) to more Fe-rich plagioclase-phyric sections in the middle (Units 5, 6, 7 and part of 9), and a highly differentiated granophyre just below the top (Unit 8). Whole-rock compositions reflect this textural subdivision; differentiation toward the granophyre is accompanied by an increase in SiO₂, Fe/Mg and incompatible elements, with decrease of Mg and Ca (Travis et al. 1971, Phillips 1986). Regional greenschist-facies metamorphism stabilized actinolite – albite – chlorite – epidote – quartz assemblages in the dolerite, but throughout the Golden Mile area the metamorphic assemblage has been overprinted by carbonate-, muscovite- and pyrite-bearing assemblages. Three alteration zones have been mapped: i) a chlorite zone representing weak carbonation of the metamorphic assemblage, ii) a carbonate zone representing more local, intense carbonation, and iii) a pyrite zone representing sulfidation and gold addition in and around zones of ductile shear (Phillips 1986). The texture of the dolerite is typically massive; it preserves relic igneous features, except for local strongly foliated zones that define 1- to 2-m thick zones of ductile shear.

Chlorite is the dominant Fe-Mg-bearing mineral in the chlorite zone, where it overgrows and pseudomorphously replaces actinolite; some calcite and ankerite are also produced during actinolite breakdown. Other phases include quartz, albite, magnetite and ilmenite. Except in the shear zones, magmatic textures are commonly preserved.

The carbonate zone appears bleached owing to the predominance of carbonates over chlorite. Ankerite and siderite are the dominant phases, although up to 10% chlorite may remain. Chlorite from the carbonate zone [Fe₂₈Al₇Mg₁₅(Si₂₈Al₁₂)O₁₀(OH)₈] is

<table>
<thead>
<tr>
<th>Section</th>
<th>Mine Level</th>
<th>Dolerite Unit</th>
<th>Carbonates</th>
<th>Alteration Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000</td>
<td>4 (130 m)</td>
<td>9</td>
<td>Ankerite</td>
<td>Mainly chlorite zone with 2 m pyrite zone in centre.</td>
</tr>
<tr>
<td>2100</td>
<td>4 (130 m)</td>
<td>9</td>
<td>Siderite</td>
<td>Major shear zone in centre.</td>
</tr>
<tr>
<td></td>
<td>13 (430 m)</td>
<td>9 to 8</td>
<td>Ankerite</td>
<td>Predominantly chlorite zone to west. Carbonate zone to east.</td>
</tr>
<tr>
<td>1000</td>
<td>3 (100 m)</td>
<td>9 to 8 to 7</td>
<td>Siderite</td>
<td>Several large shear zones in the section, mainly carbonate zone.</td>
</tr>
</tbody>
</table>

Mine levels are approximate depths below ground level, correlating with Fig. 1.
less iron-rich than that from the chlorite zone
\([\text{Fe}_{3.3}\text{Al}_{1.5}\text{Mg}_{1.3}(\text{Si}_{2.5}\text{Al}_{1.5})\text{O}_{10}(-\text{OH})_2]\) in unit 8 and
\([\text{Fe}_{3.3}\text{Al}_{1.5}\text{Mg}_{1.4}(\text{Si}_{2.6}\text{Al}_{1.4})\text{O}_{10}(-\text{OH})_2]\) in unit 9. Quartz
and muscovite are more abundant, and other minor
phases include tourmaline, pyrite, paragonite and
chalcopyrite.

The pyrite zone is characterized by introduced
cherty vein-material. A foliation defined by musco-
vite is better developed adjacent to, and within, the
pyrite zone, and represents considerable overprint-
ing of relict igneous textures. Modal quartz increases
from the chlorite to the carbonate zones and to the
quartz-rich pyrite zone. Although economic gold
(pyrite zone) occurs in all units of the dolerite, the
type and thickness of alteration are strongly con-
trolled by dolerite stratigraphy (Phillips 1986). The
general immobility of most major elements during
gold-related alteration is partly responsible for this
stratigraphic control.

Although carbonate alteration around Archean
gold deposits has been tacitly assumed to be early,
possibly related to sea-floor alteration (Davies et al.
1982, Fyon & Crocket 1982, Karvinen 1982), Bar-
tram & McCall (1971) suggested a post-peak-of-
metamorphism age for carbonate alteration at Kal-
goorlie. M.G. Fotios (written comm. 1983) con-
firmed this timing by showing that chlorite-zone
assemblages (chlorite – calcite) overprint regional
metamorphic actinolite. Phillips (1986) suggested
that chlorite alteration, carbonate alteration, pyrite
alteration and gold mineralization were all part of
one essentially synchronous event contemporaneous
with progressive deformation.

In this paper, initial discussion of host-rock con-
trol is confined to the zones of chlorite and carbonate
alteration, in which siderite, calcite and ankerite are
stable. Sulfidation (pyrite zone) stabilizes dolomite
locally and is discussed separately.

**HOST-ROCK CONTROL ON CARBONATE ASSEMBLAGES IN THE ZONES OF CHLORITE AND CARBONATE ALTERATION**

There is a systematic distribution of carbonate
minerals throughout the zones of chlorite and car-
bonate alteration within the Golden Mile Dolerite.
Ankerite is found in all units of the dolerite in both
zones. Calcite occurs sporadically in the chlorite zone.
in Mg-rich units (Unit 9 and Units 1–6), but is unrecorded in the Fe-rich units (Unit 7 or 8) and in the zone of carbonate alteration. Siderite is widespread in the zone of carbonate alteration in the Fe-rich units (Units 7, 8 and 9), but is scarce in Units 1–6 and upper Unit 9 (e.g., less differentiated part of the dolerite). This pattern of distribution reflects whole-rock compositional trends in the dolerite, in that siderite is abundant in Fe-rich units of the sill, and calcite in the more Mg-rich units. All carbonate compositions can be adequately represented by variations in Fe–Mg–Ca (Fig. 2), as MnCO₃ is typically less than 1.5% (molar basis). Routine identification of phases was made by X-ray diffraction, and compositions were determined by electron microprobe (see Appendix).

A total of 122 analyses of ankerite (Tables 2, 3, 4, 5) were recorded from the chlorite and carbonate zones. The most Fe-rich ankerite, which contains on average 34.5% FeCO₃ and 13.8% MgCO₃, places limits on the temperature of equilibration (Essene 1983); this is discussed below. In general, the ankerite from Unit 8 is slightly more FeCO₃-rich (26–32%) than that from Unit 9 (20–29%), though there is considerable overlap. Three samples from the most differentiated part of the dolerite sill (2518, 2520, 2524) are particularly Fe-rich (Table 4).

Forty-four analyses of siderite (Tables 3, 4, 5) from the chlorite and carbonate zones show that it contains between 15 and 30% MgCO₃ in solid solution, with minor CaCO₃ (0–2%) and MnCO₃ (up to 2%). The more Fe-rich siderite (75–83% FeCO₃) is from the chlorite and carbonate zones of Unit 8 and upper Unit 7 (cf. 70–80% FeCO₃ in Unit 9).

On the basis of eleven analyses (Tables 3 and 4), the calcite shows high Fe/Mg, approximately 3–4% FeCO₃, and MnCO₃ and MgCO₃ both less than 1.5%. The two calcite-bearing samples come from different sections in Unit 9.

Carbonate distribution within the Golden Mile Dolerite closely reflects host-rock composition, and to a lesser extent, the degree of alteration. The Mg-rich units (e.g., unit 9) of the dolerite stabilize chlorite – ankerite ± calcite assemblages, even close to the shear zones, whereas Fe-rich units (e.g., upper unit 7, unit 8) stabilize siderite over wide areas at the expense of chlorite and calcite (Fig. 3). This leads to a thicker zone of carbonate alteration in the more Fe-rich units (Phillips 1986), but is not directly related to either gold grade or inferred activity of carbon dioxide (i.e., compared to Mg-rich units, Fe-rich compositions favor the breakdown of chlorite-bearing silicate assemblages to carbonates, given a constant composition of the fluid).

TABLE 2. COMPOSITION OF ANKERITE, LEAST DIFFERENTIATED DOLERITE

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Distance (m)</th>
<th>Unit</th>
<th>Alteration Zone</th>
<th>Fe</th>
<th>Mg</th>
<th>Mn</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>3002</td>
<td>0.6</td>
<td>9</td>
<td>Chl</td>
<td>24.6</td>
<td>4.6</td>
<td>1.0</td>
<td>5.0</td>
</tr>
<tr>
<td>3028</td>
<td>10.0</td>
<td>9</td>
<td>Chl</td>
<td>24.4</td>
<td>4.0</td>
<td>1.0</td>
<td>5.0</td>
</tr>
<tr>
<td>3053</td>
<td>12.0</td>
<td>9</td>
<td>Chl</td>
<td>24.3</td>
<td>4.0</td>
<td>1.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No. of analyses</th>
<th>2</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>100Fe/(Fe+Mg)</td>
<td>50</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

Expressed in atomic %. All samples from 3000 section. Distances measured from collar of hole.

**Temperature of Carbonate Formation**

Two methods of estimating temperature are applicable to carbonate assemblages. Coexisting calcite—
Iips 198Q, a temperature estimate can be made for the rile, carbonafe, pyrite and gold were qmchronous @hil- ture @ssene 1983). Assuming that formation of chlo-
the most F+rich ankerile places a limit on tempera-
t(t 40°C) using the thermometer of Powell et a.
(1984). Multiple analyses demonstrate homogeneity of
given the low proportions of MnCO3 in all car-
tion went. Manganese is unlikely to affect this resuft,
the carbonate pairs coerdsted at tle time of the altera-
SurrpauoN AND rrs Covrnor oN Cansoere
400'C for the Golden Mile.
mated 400'C), in accord with temperatures below
rock compositions. The most Fe-rich ankerite from the
permitting more Fe-rich ankerite in appropriate host'
along the FecalCorlz - MgCatCOrl2 join decreases,
ture. With increasing temperature, the miscibility gap
can be used to verify the above estimates of tempera-
derived from primary fluid-inclusions in quartz veins
Wilson 1983), but totally consistent with temperatures
values in separated pyrite and anhydrite (Golding &
is considerably higher than that based on sulfin-isotope
attribute estimate from carbonates fromthe Golden Mle
compositions, and textural relationships suggest that
zones of ductile shear within the dolerite represents
sulfur addition in rather restricted loci that coincide
with economic Au mineralization. Pyrite typically
comprises 2–10% of the altered dolerite in the pyrite
zone and is accompanied by muscovite, ankerite, quartz
and albite.

Samples from the 2-m thick pyrite zone from
upper Unit 9 (3000 section, see Table 1) have highly
heterogeneous compositions of ankerite and a com-
plete gradation from Fe-poor dolomite (Fig. 4). This
spread of carbonate compositions (Table 6) is not
found in either the carbonate zone or chlorite zone
(Fig. 2), but is displayed by three samples from the
pyrite zone in Unit 9 (3040, 3042, 3045) and two
samples in Unit 7 (1030, 1038). A representative
range in ankerite compositions within a single sam-
pile is from ca. 52% FeCa(CO3)2 to ca. 10% FeCa(CO3)2.
These wide ranges occur within a single
thin section and are closely related to areas of pyrite
concentration. Dolomite is almost invariably
associated with the most pyrite-rich areas, in particu-
larly with areas of fine granular pyrite along the
margins of quartz veins.

Siderite is uncommon in the pyrite zone. The over-
Table 3. Composition of Calcite and Siderite, More Differentiated Dolerite

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>1002</th>
<th>1017</th>
<th>1020</th>
<th>1024</th>
<th>1028</th>
<th>1032</th>
<th>1045</th>
<th>1050</th>
<th>1068</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m)</td>
<td>2.5</td>
<td>22.9</td>
<td>27.8</td>
<td>28.9</td>
<td>30.8</td>
<td>32.0</td>
<td>38.9</td>
<td>49.4</td>
<td>65.3</td>
</tr>
<tr>
<td>Unit</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Alteration Zone</td>
<td>Carb/Chl Chl Carb</td>
<td>Carb</td>
<td>Carb</td>
<td>Carb</td>
<td>Carb</td>
<td>Carb</td>
<td>Carb</td>
<td>Carb</td>
<td></td>
</tr>
</tbody>
</table>

**Ankerite**

- Fe: 26.3, 28.0, 28.8, 30.1, 31.8, 27.4, 28.2, 28.6, 28.9
- Mn: 1.0, 1.1, 0.8, 0.8, 0.7, 0.9, 1.0, 0.6, 0.6
- Mg: 20.6, 20.2, 19.0, 17.4, 17.4, 20.6, 19.9, 20.1, 20.0
- Ca: 50.2, 50.7, 50.4, 51.6, 50.1, 51.1, 50.9, 50.7, 50.4
- No. of analyses: 5, 2, 4, 2, 6, 4, 6, 4, 6
- 100Fe/(Fe+Mn+Mg): 56-58, 56-58, 56-64, 56-64, 60-64, 60-64, 56-60, 56-60, 55-62

**Siderite**

- Fe: 75.1, 80.1, 80.5, 77.2, 77.4
- Mn: 1.8, 1.6, 1.9, 0.8, 1.4
- Ca: 0.9, 2.0, 0.8, 1.5, 1.1
- No. of analyses: 5, 3, 5
- 100Fe/(Fe+Mn+Mg): 74-80, 80-83, 81, 77-80, 75-80

Expresed in atomic %. All samples from 1000 section. Distances measured from collar of EHR.

All spread of siderite compositions in this zone is similar to that found in the zones of chlorite and carbonate alteration (Fig. 4). However, the most Fe-rich siderite (83% FeCO₃) occurs in the pyrite zone of Unit 7.

The heterogeneity of the ankerite and the scarcity of siderite in the pyrite zone can be accounted for by incorporation of much of the iron into pyrite in response to sulfidation. The inferred high activity of sulfur stabilizes pyrite, leaving the remaining silicate assemblage with relatively low Fe/(Fe+Mg+Ca). There is no evidence that the distribution of ankerite versus dolomite is controlled by variations in whole-rock Fe:Mg:Ca proportions. The compositional variations in ankerite and dolomite across thin sections are explained in terms of small-scale variations in sulfur activity; i.e.,

\[
\text{FeCO}_3 + 2\text{H}_2\text{S} = \text{FeS}_2 + \text{H}_2\text{CO}_3 + \text{H}_2
\]

in "ankerite" in fluid pyrite fluid

Importantly, small areas of pyrite within a thin section are positively correlated with more Mg-rich compositions of dolomite and ankerite.

Carbonates in Greenstone Belts

A marked feature of many greenstone belts is the widespread and commonly intense carbonate alteration of several rock-types. The principles governing alteration mineralogy developed for the Golden Mile Dolerite can readily be extended to include other lithologies.

The nature of fluids during the metamorphism of greenstone belts is particularly important in discussions of carbonate alteration. Direct measurements of fluid composition based on fluid inclusions are available for numerous gold deposits in Western Australia, southern Africa and Canada (Smith et al. 1984, Ho et al. 1985). The fluids associated with mineralization are typically rich in H₂O and CO₂, of low salinity, and inferred to be metamorphic in origin (Kerrich & Fryer 1979, Groves et al. 1981, Phillips & Groves 1981, Phillips & Groves 1983, Gilling & Wilson 1983). The importance of H₂O—CO₂ fluids in determining carbonate mineralogy is twofold; clearly they are a possible source for CO₂, but also their inferred near-neutral to slightly alkaline nature (Phillips & Groves 1983, Ho et al. 1985) controls the mobility of major elements.

These concepts can be extended to other litholo-
CARBONATE ASSEMBLAGES IN GOLDEN MILE DOLERITE, KALGOORLIE

Fig. 4. Representative carbonate compositions (in atomic proportions of Ca, Mg and Fe) from the pyrite zone: 1000 section (left), 3000 section (right). Single samples show complete trends from Fe-rich ankerite to dolomite.

Table 6. Extreme composition of calcite and siderite, pyrite alteration zone

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>1030</th>
<th>1038</th>
<th>3040</th>
<th>3042</th>
<th>3045</th>
</tr>
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<tbody>
<tr>
<td>Distance (m)</td>
<td>31.4</td>
<td>36.1</td>
<td>14.8</td>
<td>14.95</td>
<td>15.1</td>
</tr>
<tr>
<td>Unit</td>
<td>7</td>
<td>7</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

**ANKERITE - DOLOMITE**

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>Mn</th>
<th>Mg</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>26.0</td>
<td>2.6</td>
<td>29.1</td>
<td>80.7</td>
</tr>
<tr>
<td>Mn</td>
<td>0.9</td>
<td>0.9</td>
<td>0.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Mg</td>
<td>22.6</td>
<td>29.8</td>
<td>29.9</td>
<td>29.8</td>
</tr>
<tr>
<td>Ca</td>
<td>50.6</td>
<td>51.1</td>
<td>51.0</td>
<td>76.0</td>
</tr>
<tr>
<td>No. of analyses</td>
<td>10</td>
<td>6</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>100Fe/(Fe+Mn+Mg)</td>
<td>10-53</td>
<td>34-59</td>
<td>3-33</td>
<td>1-15</td>
</tr>
</tbody>
</table>

**SIDERITE**

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>Mn</th>
<th>Mg</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>80.7</td>
<td>75.2</td>
<td>83.1</td>
<td>80.5</td>
</tr>
<tr>
<td>Mn</td>
<td>1.4</td>
<td>1.5</td>
<td>1.6</td>
<td>1.9</td>
</tr>
<tr>
<td>Mg</td>
<td>17.5</td>
<td>22.4</td>
<td>14.0</td>
<td>14.9</td>
</tr>
<tr>
<td>Ca</td>
<td>0.4</td>
<td>0.9</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>No. of analyses</td>
<td>6</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100Fe/(Fe+Mn+Mg)</td>
<td>76-81</td>
<td>81-84</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Expressed in atomic %. Distances measured from collar of DDN.

Nickel deposits occur in banded iron-formation, where large-scale structural and textural evidence suggests an origin by metamorphic replacement (MacDonald,1983, Phillips et al. 1984). The carbonate mineral in these deposits is dominantly siderite (reflecting the iron-rich host rocks); a reconnaissance study shows that the composition of siderite is locally more Mg-rich near pyrrhotite than in sulfide-poor areas (G.M. Woad, written comm. 1981).

The broad association, within greenstone belts, of nickel deposits with rocks of the komatiitic suite (e.g., Marston et al. 1981), and of many major gold deposits with Fe-rich host rocks (generally mafic volcanic or intrusive rocks, and banded iron-formations), implies that the typical carbonate assemblages near nickel deposits and gold deposits are quite different, and reflect their respective host-rocks.

**SUMMARY**

The distribution of ankerite, siderite and calcite within the Golden Mile Dolerite is strongly controlled by the bulk-rock composition of the host. Siderite
Fet. Ca-Mg-Fe plot of carbonate assemblages common in Archean greenstone belts. Magnesite (1) and magnesite–dolomite assemblages (2) are typical of ultramafic sequences (e.g., Pearton 1980, Donaldson 1981). Dolomite + calcite + ankerite (3, 4, 5) assemblages are common in mafic host-rocks (e.g., Phillips & Groves 1984). Siderite–ankerite (6) is typical of more differentiated mafic rocks such as the Golden Mile Dolerite, and siderite (7) is common in banded iron-formation.

is abundant in Fe-rich units, calcite in more Mg-rich host rocks, and ankerite is widespread. The predictable pattern of their distribution implies that broadscale equilibrium was achieved during stabilization of the carbonate-bearing assemblages in the zones of chlorite and carbonate alteration. In contrast, the compositional variations in ankerite and in dolomite in the pyrite zone suggest variations in physicochemical parameters (e.g., sulfur activity) even on the scale of a single thin section.

Temperatures of ca. 300–350°C derived from coexisting calcite–ankerite pairs are in accord with fluid-inclusion data and provide a temperature for the main event of gold mineralization. The principles governing the distribution of carbonate species within the Golden Mile Dolerite have wider applicability than just at Kalgoorlie, and can be used to rationalize the mineralogy of other altered rock-types in greenstone belts.

Acknowledgements

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APPENDIX: ANALYTICAL PROCEDURE

All carbonate analyses were performed using energy dispersion on the MAC electron microprobe at CSIRO, Floreat Park, Western Australia. The generally fine grain-size and common intergrowths precluded significant widening of the 1–3 μm beam, a technique that would be more applicable to coarser-grained rocks (Essene 1983); however, count times were reduced from 100 seconds to 40 seconds. An operating voltage of 15 kV was used for all analyses. A number of replicate analyses were made initially to evaluate the degree of volatilization of the carbonates under these conditions. There was found to be very little loss of volatile components. Small mineral inclusions were readily detected during the analysis of carbonates. Nearby chlorite grains were avoided when choosing areas for analysis. Small amounts of SiO2 were attributed to quartz and were disregarded, whereas analyses showing TiO2 were usually rejected owing to possible contamination by ilmenite.