MINERALOGY AND CHEMISTRY OF PROTEROZOIC MAGNESITE ORES FROM SOUTH AUSTRALIA

J.L. Keeling\textsuperscript{1}, S.G. McClure\textsuperscript{2} and M.D. Raven\textsuperscript{2}

\textsuperscript{1} Primary Industries and Resources, South Australia
\textsuperscript{2} CSIRO Land and Water

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MINERALOGY AND CHEMISTRY OF PROTEROZOIC MAGNESITE ORES FROM SOUTH AUSTRALIA

J.L. Keeling¹, S.G. McClure and M.D. Raven

ABSTRACT

The chemistry and mineralogy of samples from six Proterozoic magnesite prospects in the northern Flinders Ranges and Willouran Ranges, South Australia were investigated using ICP, quantitative XRD and SEM. The samples represent two different styles of magnesite deposit namely: 1) sedimentary - replacement and 2) sedimentary - chemical with reworked clastic deposits.

The Balcanoona prospect is a sedimentary - replacement deposit and forms irregular bodies of coarse, crystalline sparry magnesite replacing pre-existing sedimentary dolomite of Balcanoona Formation. Magnesite crystals range in size from 2 to 30 mm. Balcanoona magnesite ore has an average Fe₂O₃ content of 1.5% and a CaO content of 1.7%. Both Fe and Ca are present and substitute for Mg in magnesite. Chlorite is the dominant minor mineral phase with accessory quartz, apatite and trace amounts of pyrite. Non-carbonate mineral phases form mainly along magnesite crystal boundaries. Fe, P and Mn contents are higher than for sedimentary-chemical magnesite ores but CaO content is lower. Compared with sedimentary-chemical magnesite ores, trace element chemistry in Balcanoona magnesite shows lower concentrations of Sr and B and slightly higher Zr and Th. Traces of organic substance were recorded in one sample.

Samples from Screechowl Creek, Witchelina, Termination Hill, Myrtle Springs and Mount Hutton are all sedimentary -chemical deposits formed as shallow marine or marginal marine deposits. The original layered chemical sediments have often been reworked to form coarse clastic deposits that are thinly interbedded with dolomite. Magnesite is present predominantly as cryptocrystalline particles 1-5 µm in size. Iron content is comparatively low, ranging from Fe₂O₃ 0.08% at Witchelina to 0.39% at Myrtle Springs. Calcium content is relatively high ranging from CaO 2% at Mount Hutton to 4.5% at Screechowl Creek. Calcium is present as dolomite or magnesian calcite usually as a slightly coarser crystalline phase mostly in the matrix around magnesite clasts, and as veinlets. In bedded chemical sediments the composition of individual layers may change from dominantly magnesitic to dolomitic. Cryptocrystalline magnesite contains persistent but low levels of Ca and Si. Talc is the dominant minor phase; quartz is present in minor to trace amounts mainly as fine sand grains; other phases include trace amounts of albite, K-feldspar and organic matter.

1.0 INTRODUCTION

¹ Primary Industries and Resources, South Australia.
Magnesite (MgCO₃), as a minor component, is widely associated with Proterozoic sedimentary dolomite units throughout the Mount Lofty, Flinders and Willouran Ranges of South Australia (Forbes & Priess, 1987). Potential economic resources of magnesite are known from the northern Flinders Ranges and Willouran Ranges where magnesite is found as thinly bedded conglomerates and layered chemical sediments in Skillogalee Dolomite, and as coarsely crystalline aggregates replacing dolomite in Balcanoona Formation (Crettenden, 1985).

During April - May 1997, samples of magnesite ore were collected by J.L. Keeling, A.M. Pain and W.V. Priess (Primary Industries and Resources, South Australia) from six magnesite prospects as part of an assessment of these resources for use as feedstock for magnesium metal production. The resource assessment is part a pre-feasibility study for the proposed development of a magnesium metal production facility in the northern Spencer Gulf region of South Australia.

Quantitative mineralogy and chemistry of bulk composite ore samples from each of the prospects were determined using X-ray diffraction and ICP analysis. Selected samples were examined by electron microscopy to characterise the mineralogy of the magnesite and associated mineral phases.

2.0 SAMPLES

Representative bulk magnesite samples (215347, 215348, 215350-53) from 6 magnesite prospects were collected in the field either by subsampling existing ore stockpiles or by chip sampling across individual magnesite beds as summarised in Table 1. In addition, one bulk sample representative of interbedded dolomite (sample 215349) was collected from the Screechowl Creek Prospect. Bulk samples were crushed at Australian Mineral Development Laboratories (AMDEL) Ltd to <2 mm size from which further subsamples were taken for chemical analyses, X-ray diffraction and preliminary acid leach tests.

For electron microscope and petrographic studies, selected samples were collected in the field as representative of individual magnesite beds or were chosen from stockpiled ore. These were supplemented with samples collected from previous investigations (Crettenden, 1985). Petrographic studies were undertaken by Mason Geoscience Pty Ltd with results reported in Mason (1997).
### TABLE 1: Summary of Magnesite Samples

<table>
<thead>
<tr>
<th>Locality</th>
<th>Sample No.</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balcanoona</td>
<td>Bulk 215347</td>
<td>Average of stockpiled ore from adits 1 to 3.</td>
</tr>
<tr>
<td></td>
<td>SEM 3656</td>
<td>Sparry crystalline magnesite: selected sample No.1 adit.</td>
</tr>
<tr>
<td></td>
<td>SEM 3657</td>
<td>Sparry crystalline magnesite: selected sample No.2 adit.</td>
</tr>
<tr>
<td></td>
<td>SEM 3715</td>
<td>Creek sample below No.3 adit (bedding traces apparent).</td>
</tr>
<tr>
<td></td>
<td>SEM 3716</td>
<td>Stockpiled ore: grey, coarsely crystalline magnesite.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stockpiled ore from adits 1 to 3.</td>
</tr>
<tr>
<td>Screechowl Creek</td>
<td>Bulk 215348</td>
<td>Composite chip sample across 12 individual magnesite beds.</td>
</tr>
<tr>
<td></td>
<td>Bulk 215349</td>
<td>Composite chip sample of dolomite interbeds.</td>
</tr>
<tr>
<td></td>
<td>SEM 3721</td>
<td>Bedded magnesite, weathered.</td>
</tr>
<tr>
<td></td>
<td>SEM 3722</td>
<td>Medium magnesite conglomerate, minor dark grey matrix.</td>
</tr>
<tr>
<td></td>
<td>SEM 3724</td>
<td>Bedded magnesite lower section Unit 11, minor dark feldspar crystals.</td>
</tr>
<tr>
<td>Witchelina</td>
<td>Bulk 215350</td>
<td>Composite chip sample of 4.5 m thick magnesite bed.</td>
</tr>
<tr>
<td></td>
<td>SEM 3661</td>
<td>Selected subrounded, pebble magnesite conglomerate, western syncline limb.</td>
</tr>
<tr>
<td></td>
<td>SEM 3741</td>
<td>Sandy to granular magnesite, western syncline limb.</td>
</tr>
<tr>
<td>Termination Hill</td>
<td>Bulk 215351</td>
<td>Composite chip sample across 24 individual magnesite beds.</td>
</tr>
<tr>
<td></td>
<td>SEM 3725</td>
<td>Bedded magnesite with minor small feldspar crystals.</td>
</tr>
<tr>
<td></td>
<td>SEM 3740</td>
<td>Coarse magnesite conglomerate.</td>
</tr>
<tr>
<td>Myrtle Springs</td>
<td>Bulk 215352</td>
<td>Sample from No.3 Quarry coarse rock stockpile.</td>
</tr>
<tr>
<td></td>
<td>SEM 3658</td>
<td>Selected sample No.3 Quarry, coarse magnesite conglomerate.</td>
</tr>
<tr>
<td></td>
<td>SEM 3723</td>
<td>Stockpile, coarse magnesite conglomerate.</td>
</tr>
<tr>
<td>Mount Hutton</td>
<td>Bulk 215353</td>
<td>Composite chip sample across 11 individual magnesite beds.</td>
</tr>
<tr>
<td></td>
<td>SEM 3717&amp;18</td>
<td>Weathered coarse sandy magnesite.</td>
</tr>
<tr>
<td></td>
<td>SEM 3719</td>
<td>Coarse sand to fine pebble magnesite with dark grey patches and banding.</td>
</tr>
<tr>
<td></td>
<td>SEM 3720</td>
<td>Fine pebble magnesite conglomerate with dark matrix.</td>
</tr>
</tbody>
</table>
3.0 METHODS

3.1 Scanning Electron Microscopy
Sample fragments for electron microscopy were sliced by diamond saw either from rock specimens selected in the field or from bulk samples as detailed in Table 1. Either sawn or freshly fractured sample surfaces were prepared for examination. All samples were cleaned in alcohol, mounted onto aluminium stubs using Araldite™, cured at 105°C then evaporatively coated with 30 nm of carbon.

Samples were examined using a Cambridge Stereoscan S250 scanning electron microscope (SEM) fitted with a LINK system, energy dispersive X-ray (EDX) analyser. The investigation used both backscattered and secondary electron modes for imaging the sample surface.

3.2 X-ray Diffraction (XRD)
Crushed <2 mm bulk samples from individual prospects (Table 1) were subsampled to give 1g of sample for analysis. These were prepared by grinding with 10 ml of alcohol in a McCrone micronising mill for 10 minutes. The resulting slurries were oven dried at 105°C, mixed in an agate mortar and pestle, then lightly back pressed into steel sample holders for XRD analysis. XRD patterns were recorded with a Philips PW 1800 microprocessor-controlled diffractometer using Co Kα radiation, variable slit, and graphite monochromator. The diffraction patterns were recorded in steps of 0.05° 2θ with a 1.0 second counting time per step, and logged to permanent files on an IBM-compatible PC for analysis.

Rietveld quantitative analysis was performed on the XRD data using the commercial package SIROQUANT from Sietronics Pty Ltd. Background was subtracted first and the data calibrated for the automatic divergence slit.

3.3 Chemical Analyses
Major oxides and trace elements were determined for crushed bulk samples only. This was done initially by Australian Mineral Development Laboratories (Amdel) using ICP for major oxides and trace elements with the exceptions of:

- CO₂ determined by a gravimetric technique, and
- Boron by colorimetric method.

Check analyses were made at CSIRO Land and Water for CO₂ by Leco furnace method and for K, Na, S and B by ICP using hot nitric acid digestion.
4.0 RESULTS

4.1. Scanning Electron Microscopy
Electron micrographs and EDX analyses are presented in full in Appendix A. A summary of the results is given below.

4.1.1 Balcanoona Magnesite
- **Magnesite**: Cleavage planes of coarse magnesite crystals were characterised by the presence of numerous small voids (fluid inclusions?) mainly as negative crystals, typically <10 µm across (Plates 1 & 2). Magnesite also contains patches where calcium dominates over magnesium. These were not common, and varied in size from <15 µm to several 100 µm (Plates 2 & 10). The presence of a trace of cerium phosphate was recorded in a calcium-rich area in one sample (Plate 2). EDX analyses of magnesite showed Fe in the magnesite crystal structure (Figs A1, A3-8).

Other mineral phases were concentrated mainly along magnesite crystal boundaries and included:
- **Chlorite** as curved thin flakes from 10-200 µm across (Plates 3 & 4). Composition of chlorite was Mg rich but always with some Fe present.
- **Apatite** as irregular grains and granular masses 2-100 µm diameter (Plates 3, 4, 7) and rarely as euhedral crystals (S1, Plate 4).
- **Dolomite** and Mg-calcite as minor granular particles with chlorite and apatite (Plate 7) as well as discrete areas within individual magnesite crystals as described above.
- **Pyrite** as rare euhedral pyriohedral crystals (Plate 9).
- **Fe and Ti oxides** as small inclusions in chlorite-rich areas (Plate 8).
- **Gypsum** was recorded with chlorite in one sample (Plates 5 & 6).

4.1.2 Magnesite interbeds in Skillogalee Dolomite
Samples from Screechowl Creek, Witchelina, Termination Hill, Myrtle Springs and Mount Hutton are all included in this group and have many characteristics in common. Magnesite sedimentary rocks from these prospects include finely laminated chemical sediments which may be locally disrupted to produce intraformational conglomerate, or reworked and deposited as coarse sand, granule and pebble conglomerate. Pebble conglomerate was common at all prospects; bedded magnesite was much less common and was best represented at Screechowl Creek and Termination Hill prospects; sandy and granular magnesite beds were more significant at Myrtle Springs and Mount Hutton prospects.

- **Magnesite**: The magnesite in all samples was predominantly cryptocrystalline as irregular rhombohedral crystallites 1 µm to 8 µm in size (Plates 14, 15, 35, 40). Individual crystals were partly fused together but also appeared to enclose numerous voids of size range similar to that of the crystallites. Cryptocrystalline magnesite invariably included some calcium (Ca) and silica (Si) (Figs A8, A10, A12-15, A18-20, A22, A23, A25-30). At Termination Hill, fine dark laminae in bedded magnesite corresponded with more dolomitic composition and the presence of some organic
matter (Plates 30, 33, Fig. A18). In other samples darker grey patches or bands were magnesite of identical composition to light grey and white areas (Plates 12-15, Fig. A8; Plate 34, Fig. A19). Minor recrystallised, microcrystalline to sparry, magnesite was also present in most samples as a component of either thin veinlets or of the matrix between magnesite clasts in conglomerates. Recrystallised magnesite formed granular particles and aggregates with individual grains 5-50 µm diameter (Plates 28, 29, 36, 37, 39, 55). These were generally pure with little or no detectable silica or calcium but occasionally with some iron (Figs A15, A16(S1), A20(S6), A21, A30(S9)). In the majority of cases, recrystallised magnesite grains were invariably intermixed with dolomite, Mg-calcite or talc of similar grain size.

Non-magnesite phases included:

- **Dolomite and Mg-calcite** were present mostly as recrystallised, microcrystalline grains either forming the matrix around magnesite clasts (Plates 20, 28, 29, 48) or as thin veinlets that cut across bedding and magnesite clasts (Plates 17, 23, 37, 39). Pure calcite was rarely present, but the distinction between areas of Mg-calcite and dolomite was difficult from EDX data because Mg X-rays are of lower energy which makes them more susceptible to absorption. The relative intensity of Mg to Ca, as recorded, can therefore be suspect, particularly when working with samples with rough surfaces. Dolomite was observed in sample 3725 from Termination Hill (Plates 30 & 33) as cryptocrystalline particles in thin laminae within bedded magnesite. The cryptocrystalline dolomite layers also contained some organic matter (Fig. A18). While variation in composition of primary sediment from magnesite to dolomite was rarely observed at the microscopic scale this was suspected from field mapping to be a characteristic of bedded magnesite. Within individual magnesite clasts, irregular patches of dolomite alteration were occasionally observed (Plates 41 & 42) and confirm larger scale replacements of magnesite by dolomite observed in the field. In veins of sparry Mg-calcite, strontium (Sr) was sometimes recorded (Figs A20 & A21), indicating that trace amounts of Sr are mainly present as carbonate where Sr substitutes for Ca in late stage veins.

- **Talc** was the most common silicate phase in many of the samples as flakes from 5µm to 100 µm across and mostly scattered throughout the dolomitic matrix (Plates 16, 44, 47, 50). Talc was also present as flakes or veinlets in magnesite clasts (Plates 21, 23, 39, 40, 42) and as elongate crystal laths on the margins of clasts (Plates 24 & 25). Talc composition was usually pure magnesium silicate (Fig. A14) although occasionally intimately mixed with K-feldspar (Figs B12, B13). The presence of silica in cryptocrystalline magnesite is due largely to the presence of submicron size talc particles partly coating the surface of magnesite crystallites (pers comm. P Self from preliminary TEM investigations of Screechowl Creek magnesite).

- **Quartz** was observed as fine-grained sand particles of around 100 µm diameter in the matrix between magnesite clasts in sample 3740 from Termination Hill (Plate 37). Free quartz was not observed in any other samples but was recorded from optical microscopy as rare sand grains and associated with recrystallised dolomite veins (Mason, 1997).

- **Albite** feldspar was common as small (0.2-0.5 mm long), euhedral, black crystals with random orientation in bedded magnesite from Screechowl Creek and Termination Hill (Plates 22, 23, 30,
EDX analyses indicate that euhedral crystals of albite are relatively pure (Figs A13, A17). Albite crystals were rare in reworked magnesite and appear to have not been formed prior to reworking or were in part destroyed during dolomitisation of the enclosing matrix (see Mason, 1997).

- **K-feldspar** was not observed directly but is inferred from EDX analyses to be present as fine-grained particles occurring with talc in matrix and veins (Plates 21, 23; Figs A12, A13).
- **Barite** was located in one sample from Screechowl Creek as a discrete mineral phase of grain size up to 100 x 20 µm across, together with Mg-calcite in a veinlet (Plate 17).
- **Organic matter** was rare but suspected to be present with primary dolomite from Termination Hill based on the presence of S, P and Cl in EDX analyses (Fig. A18), and was observed in microcrystalline dolomitic matrix in Witchelina sample 3741 (Plate 29; Fig. A16).

4.2. **X-Ray Diffraction (XRD)**

Results of Rietveld quantitative XRD are presented in Table 2. Values in parenthesis are errors estimated in the last significant figure derived from the Rietveld analysis. Some mineral phases present in minor or trace amounts will not be detected by XRD as the diagnostic X-ray reflections are not significantly above background.

**TABLE 2:** Quantitative Mineralogy by Rietveld Analysis of XRD Results (wt%)

<table>
<thead>
<tr>
<th></th>
<th>Balcanoona Magnesite 215347</th>
<th>Screechowl Creek Magnesite 215348</th>
<th>Witchelina Magnesite 215350</th>
<th>Termination Hill Magnesite 215351</th>
<th>Myrtle Springs Magnesite 215352</th>
<th>Mount Hutton Magnesite 215353</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnesite</td>
<td>95.3(4)</td>
<td>80.3(4)</td>
<td>86.8(4)</td>
<td>87.6(3)</td>
<td>85.8(5)</td>
<td>89.2(5)</td>
</tr>
<tr>
<td>Dolomite</td>
<td>3.7(2)</td>
<td>13.6(2)</td>
<td>8.5(2)</td>
<td>6.1(2)</td>
<td>7.2(2)</td>
<td>4.8(2)</td>
</tr>
<tr>
<td>Talc</td>
<td>-</td>
<td>5.3(4)</td>
<td>4.8(4)</td>
<td>3.8(3)</td>
<td>6.8(5)</td>
<td>5.9(4)</td>
</tr>
<tr>
<td>Quartz</td>
<td>0.3(1)</td>
<td>0.7(1)</td>
<td>0.1(1)</td>
<td>2.5(1)</td>
<td>0.3(1)</td>
<td>0.2(1)</td>
</tr>
<tr>
<td>Chlorite</td>
<td>0.7(3)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td><strong>99.9</strong></td>
<td><strong>100.2</strong></td>
<td><strong>100</strong></td>
<td><strong>100.1</strong></td>
<td><strong>100.1</strong></td>
</tr>
</tbody>
</table>
4.3 Chemical Analyses

Results of full chemical analyses for major oxides and trace elements are given in Table 3. Using these results, together with data from SEM and XRD, the percentages of mineral phases present in each sample were calculated by a process of rational analysis (Table 4). The procedure adopted was as follows:

- For sample 215347, all $\text{P}_2\text{O}_5$ was allocated to apatite.
- Residual Ca in sample 215347 and all Ca in samples 215348-215353 was allocated to dolomite.
- Residual $\text{CO}_2$ was allocated to magnesite.
- All $\text{Na}_2\text{O}$ was allocated to albite (except for sample 215347).
- All $\text{K}_2\text{O}$ was allocated to orthoclase.
- Quartz content was estimated from XRD.
- In sample 215347, residual $\text{Al}_2\text{O}_3$ was allocated to Chlorite.
- Residual silica was allocated to talc.
- In samples 215348-215353, $\text{SO}_4$ was allocated to barite, for sample 215347, S was allocated to pyrite.
- Residual $\text{Fe}_2\text{O}_3$ is reported for sample 215347 but not assigned to a mineral phase. In this sample, significant amounts of Fe substitute for Mg in magnesite but is also present as both goethite and hematite.
- All samples show residual $\text{MgO}$. Where mineralogical totals were below 100%, a proportion of this residual was used to increase the magnesite content. Increase in magnesite content, from allocation of residual $\text{MgO}$, was $\leq 1\%$.

Mineral compositions used for calculations are given in Table 5. Compositions are for “ideal” minerals or were modified based on energy dispersive X-ray (EDX) analyses from electron microscope investigations. In particular, EDX showed the close to ideal composition for albite and talc in the sedimentary magnesite samples and confirmed a low Fe content in chlorite in Balcanoona samples.
TABLE 3: Bulk Magnesite Samples; Chemical Analyses of Major Oxides (%) and Trace Elements (mg/kg) (modified from Amdel Report N831000G/97).

<table>
<thead>
<tr>
<th></th>
<th>Balcanoona Creek</th>
<th>Screechowl Creek</th>
<th>Screechowl Creek</th>
<th>Witchelina Termination Hill</th>
<th>Myrtle Springs</th>
<th>Mount Hutton</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Magnesite</td>
<td>Magnesite</td>
<td>Dolomite</td>
<td>Magnesite</td>
<td>Magnesite</td>
<td>Magnesite</td>
</tr>
<tr>
<td>MgO</td>
<td>215347</td>
<td>215348</td>
<td>215349</td>
<td>215350</td>
<td>215351</td>
<td>215352</td>
</tr>
<tr>
<td>CaO</td>
<td>46.1</td>
<td>44.3</td>
<td>21.1</td>
<td>46.5</td>
<td>45.1</td>
<td>45.9</td>
</tr>
<tr>
<td>SiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>1.67</td>
<td>4.42</td>
<td>19.9</td>
<td>3.05</td>
<td>2.36</td>
<td>2.27</td>
</tr>
<tr>
<td>FeO&lt;sub&gt;3&lt;/sub&gt;</td>
<td>1.01</td>
<td>3.40</td>
<td>20.3</td>
<td>1.75</td>
<td>4.49</td>
<td>3.77</td>
</tr>
<tr>
<td>AlO&lt;sub&gt;3&lt;/sub&gt;</td>
<td>1.48</td>
<td>0.15</td>
<td>0.29</td>
<td>0.08</td>
<td>0.21</td>
<td>0.39</td>
</tr>
<tr>
<td>NaO*</td>
<td>0.50</td>
<td>0.17</td>
<td>1.34</td>
<td>0.13</td>
<td>0.19</td>
<td>0.20</td>
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<tr>
<td>KO*</td>
<td>0.045</td>
<td>0.027</td>
<td>0.49</td>
<td>0.023</td>
<td>0.027</td>
<td>0.027</td>
</tr>
<tr>
<td>MnO</td>
<td>0.09</td>
<td>&lt;0.01</td>
<td>0.01</td>
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Trace Elements mg/kg (ppm)

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* CSIRO analysis
## TABLE 4: Calculated Mineralogy of Magnesite and Dolomite Samples.

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Residual MgO 0.81 1.37 0.84 1.81 1.58 1.13 1.25

## TABLE 5: Mineral Compositions Used for Calculations in Table 4 (wt%)
5.0 DISCUSSION

5.1 Balcanoona

Balcanoona magnesite ore is sparry, coarsely crystalline magnesite formed by replacement of original sedimentary dolomite. Magnesite crystals form radiating clusters that are intergrown and vary in size from 2 mm to 30 mm. In samples 3656 and 3715, magnesite crystals were arranged in bands which roughly parallel bedding in adjacent dolomite. Crystal growth was at approximately 90° to bedding trendlines. Field evidence suggests metasomatic alteration of dolomite by Mg-rich fluids migrating along bedding plane weaknesses followed by recrystallisation as magnesite.

Examination of magnesite cleavage fragments showed the presence of small fluid inclusions generally <10 µm across, persistent Fe in the crystal lattice, and minor calcium-rich zones. Granular magnesite was also present in irregular patches of matrix concentrated along crystal boundaries, together with dolomite/Mg-calcite, chlorite and apatite. Minerals forming the matrix were generally <200 µm across and typically between 20 µm and 80 µm in size. Quartz was not observed during SEM investigations but was reported in XRD. Any beneficiation to remove non-magnesite phases would require initial crushing of the ore to <100 µm. Beneficiated magnesite would still contain Fe and Ca in the magnesite crystal lattice. Substitution of Mg by Fe and Ca in magnesite is the principal cause of discrepancy between average magnesite percentages determined from XRD (MgCO$_3$=95%) and that determined by rational analysis of chemical data (MgCO$_3$=91%).

Compared with the sedimentary magnesite from the Skillogalee Dolomite member, Balcanoona magnesite has higher Fe$_2$O$_3$ (1.48%), MnO (0.09%) and P$_2$O$_5$ (0.11%) but lower CaO (1.67%). For trace elements, Balcanoona magnesite is characterised by low boron (B=34 ppm) and strontium (Sr=<20 ppm) and slightly higher thorium (Th=0.77 ppm) and zirconium (Zr=7.5 ppm). The low B and Sr values are consistent with the magnesite not being having formed under marine conditions.

5.2 Magnesite Interbeds in Skillogalee Dolomite

Magnesite samples from Screechowl Creek, Witchelina, Termination Hill, Myrtle Springs and Mount Hutton all show similar physical and chemical properties and probably formed as shallow marine or marginal marine chemical precipitates and are classed here as sedimentary-chemical deposits that include abundant reworked magnesite as coarse clastic sediments. Direct chemical precipitation rather than diagenetic growth of magnesite is supported by the fine grain size of the magnesite, typically 1-5 µm, and the observation that it may be interbedded with dolomite of similar grain size. The fine grain size of the magnesite particles and poor packing suggest rapid crystallisation and sedimentation, possibly under agitated conditions. Recrystallisation and growth of sparry magnesite may have been restricted by the co-precipitation of silica or Mg-rich clay, and very low metamorphic grade. A marine environment is inferred from the nature of the interbedded dolomites, which include stromatolite and cherty layers, and by the elevated levels of boron (B=97-142 ppm) and strontium (Sr=50-110 ppm).
Early diagenetic changes included consolidation through desiccation and in many cases, break up of the magnesite sediment leading to formation of intraformational conglomerate or, more often, reworking of the disrupted sediment to form pebble conglomerate and in some areas, coarse magnesite sand. Albite crystals, to 1 mm length, formed during early stages of diagenesis and are the principal repository of aluminium and sodium in the magnesite ore. In conglomerate, microcrystalline dolomite and magnesite form the cementing matrix. Minor to trace amounts of fine-grained quartz sand were observed in the matrix of samples from Termination Hill. Quartz was apparently unstable in the sedimentary environment and displays severe replacement around the margins by dolomite, leaving small angular kernels (Mason, 1997). This may also be indicative of the alkaline conditions at the time of sedimentation and later diagenesis.

Later diagenetic changes include the formation of talc and cross-cutting veinlets that comprise mostly sparry carbonate or rarely talc. Talc is present in a wide range of sizes from sub-micron particles, associated with cryptocrystalline magnesite, to millimetre sized, lath-shaped crystals growing out from the margin of magnesite clasts. Talc flakes are found in both magnesite clasts and matrix and, less commonly, as late-stage veinlets with fine-grained K-feldspar. Talc flakes in samples from Witchelina, Myrtle Springs and Mount Hutton were generally coarser grained than those from Screechowl Creek and Termination Hill. Talc formed probably during late-stage diagenesis or very low grade metamorphism either by reaction of colloidal silica with magnesite or through recrystallisation of Mg clays such as sepiolite or stevensite (Noack et al., 1989) that may have been deposited together with the magnesite. With the exception of samples from Termination Hill, the majority of SiO₂ present in sedimentary magnesite samples was in the form of talc. Carbonate veinlets comprised coarsely crystalline dolomite, Mg-calcite or magnesite. Strontium and barium were reported in veinlets with Sr substituting for Ca in Mg-calcite, and Ba as barium sulphate.

The cryptocrystalline character of the sedimentary-chemical magnesites and the present of voids between individual crystallites gives these samples a high surface area and potentially a higher reactivity to acid at lower temperatures than would be expected for the more coarsely crystalline Balcanoona ore.

27 February 1998
6.0 REFERENCES


APPENDIX A

ELECTRON MICROSCOPY AND EDX ANALYSES
BALCANOONA

Four samples were examined, 2 from the walls of adits 1 and 2, one from outcrop, and the fourth from stockpiled magnesite ore.

3656: BHP exploratory Adit 1: Sparry magnesite as white to pale grey coarse crystals 2-15 mm long as slightly radiating growths in weakly defined bands 10 mm to 15 mm thick. Minor pale green chlorite concentrated mainly at the junction of magnesite bands. Trace of yellow brown Fe oxides on sample surface. SEM examination of a freshly fractured surface (P.P. Crettenden sample, collected 1983).

3657: BHP exploratory Adit 2: Sparry magnesite as white to very pale grey, interlocking aggregates of radiating crystals 5-30 mm long. Minor, pale grey to greenish grey patches of probable fine-grained chlorite mainly along crystal boundaries. SEM examination of a freshly fractured surface (P.P. Crettenden sample, collected 1983).

3715: Creek sample: Comprises white opaque to slightly translucent magnesite crystals 4 mm to 10 mm in length arranged as intergrown radiating aggregates from subparallel lineations which appear to be continuous with bedding traces apparent in adjacent dolomite. Pale greenish-grey chlorite is concentrated along the traces and at the base of the radiating magnesite crystals. Sample collected from outcrop in the creek below Adit 3 (1997). SEM examination of a freshly fractured surface.

3716: Stockpile sample: Pale grey to opaque white, coarsely crystalline magnesite showing regular mosaic of interlocking crystals 3 - 8 mm length by 3 - 4 mm width. Minor pale yellow-orange iron oxide staining mainly on boundaries between individual crystals. SEM examination of a sawn face.
Plate 1: *Balcanoona Magnesite, Adit 1*: Detail of the surface of a cleavage plane in a single magnesite crystal showing the presence of small voids (fluid inclusions?) and some lighter areas indicating high calcium content (see Plate 2 for detail). Photo no. 56-3552, scale bar 20 µm.

Plate 2: *Balcanoona Magnesite, Adit 1*: Detail of Fig. 1 (top centre) of an area with high calcium substitution for magnesium. Minor cerium phosphate (very bright spot, S4) is also present in the high calcium area. Photo no. 56-3553, scale bar 4 µm. EDX analyses for spot sites are given in Fig. A1.
Fig. A1. Balcanoona Magnesite Adit 1: EDX spectra of elements present in magnesite cleavage fragment. Overlay spectra on S1 indicates the presence of a small amount of structural Fe substituting for Mg. For location of areas probed refer Plates 1&2.
Plate 3: *Balcanoona Magnesite, Adit 1*: Boundary between coarse magnesite crystals comprising predominantly chlorite (Ch) flakes (S6) to 100 µm across, and bright apatite grains (S5, S7) mixed together with smaller magnesite (Mg) fragments. Photo no. 56-3554, scale bar 100 µm.

Fig. A2. *Balcanoona Magnesite Adit 1*: EDX spectra of apatite and chlorite shown in Plate 3. Note relative low Fe content in chlorite (S6).
Plate 4: *Balcanoona Magnesite, Adit 2*: Boundary between coarse bladed magnesite crystals (S1) occupied by curved chlorite flakes (S3) and apatite grains (S4). Note euhedral apatite crystal, middle right, penetrating into magnesite (S2). Photo no. 57-3555, scale bar 200 µm.

![Plate 4 Image](image)

**S1: Magnesite**

**S2, S4: Apatite**

**S3: Chlorite**

Fig. A3: *Balcanoona Magnesite, Adit 2*: EDX spectra of magnesite, apatite and chlorite shown in Plate 4. Note structural Fe present in magnesite and chlorite.
**Plate 5:** Balcanoona Magnesite, Adit 2: Boundary between two coarse magnesite crystals marked by the presence of chlorite and apatite. Composition of magnesite recorded (S5, S6) and small aggregate of secondary gypsum (S7). Photo no. 57-3557, scale bar 200 µm.

**Plate 6:** Balcanoona Magnesite, Adit 2: Detail of Plate 5 showing secondary gypsum mixed with chlorite on the surface of a magnesite cleavage fragment. Photo no. 57-3558, scale bar 40 µm.
Fig. A4. Balcanoona Magnesite Adit 2: EDX spectra of elements present in magnesite cleavage fragment (see Plates 5&6). Overlay spectra on S5 and S6 indicate the presence of structural Fe and Ca with Cl probably in fluid inclusions. S7 identifies secondary gypsum (after apatite?) together with chlorite.
Plate 7: Balcanoona Magnesite, Adit 2: Detail of Plate 5 (bottom centre) showing mixture of finer grained chlorite (S10), apatite (S11), magnesian calcite (S12) and magnesite (S13) along boundary with coarse magnesite crystals. Photo no. 57-3561, scale bar 40 µm.

Fig. A5. Balcanoona Magnesite Adit 2: EDX spectra of minerals phases included between coarse magnesite crystals shown in Plate 7.
Plate 8: *Balcanoona Magnesite, Creek Sample:* Micrograph of a boundary zone (centre-left to right) between two radiating magnesite crystals. Zone contains minor inclusions of chlorite (S8) and clacite/apatite (S10) and some Fe and Ti oxides (S9). Photo no. 15-3583, scale bar 200 µm.

Fig. A6. *Balcanoona Magnesite Creek Sample:* EDX spectra of magnesite and minor mineral phases between coarse magnesite crystals. For location of spectra refer Plate 8.
Plate 9. Balcanoona Magnesite, Creek Sample: Margin of a coarse magnesite crystal marked by finer grained apatite (S14) and chlorite (S18) lower left. Note inclusion of chlorite in magnesite, S18 upper left, and euhedral pyrite, bright grain S12. Photo no. 15-3585, scale bar 100 µm.

Fig. A7. Balcanoona Magnesite, Creek Sample: EDX spectra of pyrite (S12) and chlorite (S18) inclusions in magnesite and chlorite (S18) and apatite (S14) along magnesite crystal boundary. For location of spectra refer Plate 9.
Plate 10: Balcanoona Magnesite, Stockpiled ore sample: Sawn surface through interlocking coarse magnesite crystals. Composition variation in magnesite is recorded in spectra from sites S1-S5 (see Fig. A8). Bright areas are Mg-calcite. Photo no. 16-3587, scale bar 400 µm.

Plate 11: Balcanoona Magnesite, Stockpiled ore sample: Sawn surface in magnesite showing the presence of a small rounded, 20 µm diameter, inclusion of organic material (lower centre, arrowed). Photo no. 16-3591, scale bar 20 µm.
Fig. A8. *Balcanoona Magnesite, Stockpiled Ore Sample:* EDX spectra showing variation in magnesite composition due mainly to iron (Fe) and calcium (Ca) substitution for magnesium (Mg). Silica (Si) in spectra S4 is due to the presence of nearby chlorite inclusions. Locations of analysed sites are shown in Plate 10.
SCREECHOWL CREEK
Three samples were examined, all from outcrop in creek section and selected during the bulk sampling program in April 1997.

3721: Fine-grained, massive, mid-grey bedded magnesite showing some disruption of layers to form elongate pebble intraformational conglomerate bands with slightly coarser grained and darker crystalline matrix. Within some areas of bedded magnesite, and in clasts, there are abundant equant dark grey albite crystals grown in random orientation. Thin veinlets of crystalline carbonate run parallel to and cut across bedding. The sample has a white, weathered surface with irregular patches of white to pale grey magnesite extending into the body of the rock preferentially within areas of bedded magnesite and clasts leaving the matrix darker grey. In weathered areas, traces of orange-brown staining were observed preferentially within the more coarsely crystalline matrix and around the margins of the clasts (sample SC8). SEM examination of a freshly fractured surface.

3722: Massive, regular pebble magnesite conglomerate with very pale grey magnesite as rounded subspherical granules 2-5 mm diameter partly fused together or surrounded by a medium to dark grey carbonate matrix. SEM examination of a freshly fractured surface.

3724: Massive, fine-grained, very pale grey bedded magnesite with slightly curved and truncated bedding planes outlined by thin, slightly darker magnesite bands. Bedding crosscut at almost 90° by occasional thin veinlets of slightly darker grey and slightly coarser crystalline carbonate. Traces of dark grey, equant albite crystals to about 1 mm length, showing random growth orientation (Sample 169.7 m). SEM examination of a sawn surface.
Plate 12:  *Screechowl Creek Magnesite, Sample 3721*: Bedded, fine-grained magnesite containing some coarser crystalline matrix between bedding planes. Evidence of partial desiccation and disruption to some beds (centre right). Patchy white areas result from weathering with the weathering progressing from right to left. Photo no. 3721, width of sample is 20 mm.

Plate 13:  *Screechowl Creek Magnesite, Sample 3721*: Backscattered electron micrograph of portion of Plate 12 showing fine-grained magnesite with thin bands of recrystallised matrix (lighter grey) that roughly parallel bedding. Enlargements are shown in Plates 14-16. Photo no. 21-3617, scale bar 1 mm.
Plate 14: Screechowl Creek Magnesite, Sample 3721: Area of white weathered magnesite showing open aggregates of 2-5 µm sized magnesite crystals. Overall composition given in S1 Fig. A8. Photo no. 21-3662, scale bar 10 µm.

Plate 15: Screechowl Creek Magnesite, Sample 3721: Area of dark grey unweathered magnesite showing open aggregates of 2-5 µm sized magnesite crystals. Almost identical in character to white magnesite above, with possibly less very fine particles. Overall composition given in S2 Fig. A8. Photo no. 21-3623, scale bar 10 µm.

Fig. A8. Screechowl Creek Magnesite, Sample 3721: Average compositions of white, weathered (S1) and dark grey, less weathered (S2) areas of magnesite. Despite slight variation in Mg intensity, compositions are essentially identical.
**Plate 16:** *Screechowl Creek Magnesite, Sample 3721*: Detail of more coarsely crystalline layers between fine-grained magnesite. These layers are composed of a mixture of fine and coarser crystalline magnesite (S3), dolomite (S7), talc (S5, S6) and magnesian calcite (S4). Photo no. 21-3624, scale bar 40 µm.

**Fig. A9.** *Screechowl Creek Magnesite, Sample 3721*: Composition of recrystallised magnesite and dolomite (S3, S4, S7) and talc (S5, S6). See Plate 16 for locations.
Plate 17: *Screechowl Creek Magnesite, Sample 3721*: Thin veinlet of magnesian calcite (S9) with patches of barite (BaSO₄) (S8) in very fine-grained magnesite (S10). Photo no. 21-3625, scale bar 20 µm.

Fig. A10. *Screechowl Creek Magnesite, Sample 3721*: Composition of Mg-calcite (S9) veinlet with barite (S8) crosscutting fine-grained magnesite (S10). See Plate 17 for locations.
Plate 18: Screechowl Creek Magnesite, Sample 3722: Pebble magnesite conglomerate comprising fine-grained magnesite granules 2-5 mm across in a carbonate matrix. Photo no. 22-3627, scale bar 1 mm.

Plate 19: Screechowl Creek Magnesite, Sample 3722: Detail of Plate 18, lower centre, showing the contact between magnesite clasts and carbonate cement. Photo no. 22-3626, scale bar 200 µm.
Plate 20: *Screechowl Creek Magnesite, Sample 3722*: Detail of contact (see Plate 19) between coarser crystalline dolomite/Mg-calcite (S1) matrix and fine-grained magnesite clast (S2). Photo no. 22-3628, scale bar 20 µm.

Plate 21: *Screechowl Creek Magnesite, Sample 3722*: Detail of impure magnesite clast (see Plate 19) which contains magnesite (S6-S8) ranging in size from 2-20 µm mixed with fine-grained flakes of talc (S4, S5) and occasionally muscovite (S3) plus some larger dolomite grains (S9). Trace of Fe (oxide?) present, centre right. Photo no. 22-3631, scale bar 20 µm.
Fig. A11. Screechowl Creek Magnesite, Sample 3722: Comparison of composition of crystalline matrix and finer grained magnesite making up individual clasts. Note no apparent Si and Ca associated with magnesite in the particular clast examined (refer Plate 20).

Fig. A12. Screechowl Creek Magnesite, Sample 3722: Variation in composition of a single impure magnesite clast due to the presence of other fine-grained mineral phases (Plate 21).
Plate 22: Screechowl Creek Magnesite, Sample 3724: Fine-grained bedded magnesite with crosscutting carbonate veinlets and random black, euhedral albite crystals. Photo no. 3724, specimen width 12 mm.

Plate 23: Screechowl Creek Magnesite, Sample 3724: Euhedral albite crystals to 0.6 x 0.2 mm (S2, S4, S6) in fine-grained magnesite (S12). Crosscutting veinlets comprise Mg-calcite (S8) offset by later veinlets of talc and K-feldspar (S10). Photo no. 24-3673, scale bar 400 μm.
Fig. A13. Screechowl Creek Magnesite, Sample 3724: Composition of diagenetic albite crystals (S2, S4, S6), dolomitic calcite (S8) and talc/K-feldspar veinlets, (S10), and bedded magnesite (S12) (Plate 23).
WITCHELINA
Two samples were examined, both from outcrop of the main magnesite bed on the western syncline limb.

3661: White to very pale grey magnesite pebble conglomerate with magnesite as rounded, subspherical to elongate clasts 1 mm to 15 mm diameter in a white, pale grey to grey fine-grained carbonate matrix. Numerous rounded clasts show a white border, usually <1 mm wide, which has a high (talc). SEM examination of a freshly fractured surface. Sample from P P Crettenden collection (sample 6437 RS2, collected 1983).

3741: Massive, white to pale grey coarse magnesite sand to fine granule conglomerate with subspherical, rounded, magnesite clasts 0.5-1 mm grading to rounded, subspherical to elongate clasts to 4 mm. Clasts are fused together or cemented by a slightly more crystalline darker grey carbonate matrix. SEM examination of a freshly fractured surface.
Plate 24: *Witchelina Magnesite, Sample 3661*: Contact between fine-grained magnesite clast (S2), right, and matrix of elongate subparallel talc crystals (S1). Photo no. 61-3565, scale bar 40 µm.

Plate 25: *Witchelina Magnesite, Sample 3661*: Detail of subparallel talc crystals (S4) with interspersed coarser crystalline magnesite particles (S3) at contact with fine-grained magnesite (right). Photo no. 61-3566, scale bar 40 µm.
Fig. A14. Witchelina Magnesite, Sample 3661: Composition of fine-grained magnesite clast (S2) and recrystallised matrix of talc (S1, S4) and coarser grained magnesite (S3) (Plates 24&25).
Plate 26: Witchelina Magnesite, Sample 3661: Detail of magnesite clast comprising anhedral, fine-grained magnesite particles 2-5 µm across arranged in an open porous network. Photo no. 61-3568, scale bar 10 µm.

Plate 27: Witchelina Magnesite, Sample 3741: Low magnification view showing coarse rounded clasts of fine-grained magnesite (mid-grey) cemented by a matrix of slightly coarser crystalline carbonate (light grey). Photo no. 41-3676, scale bar 200 µm.
Plate 28: Witchelina Magnesite, Sample 3641: Detail of Plate 27 showing boundary between fine-grained magnesite clast (lower right) and coarser grained matrix of magnesite (S6) and calcite (S7). Photo no. 41-3677, scale bar 40 µm.

Fig. A15. Witchelina Magnesite, Sample 3741: Composition of fine-grained magnesite clast (S5) and recrystallised matrix of magnesite (S6) and dolomitic calcite(S7) (Plate 28).
Plate 29: Witchelina Magnesite, Sample 3741: Detail of crystalline matrix composed of magnesite (S1), dolomite (S4) and Mg-calcite (S3) with rare patches of organic inclusions (fuzzy dark patches) (S2, S8). Photo no. 41-3681, scale bar 40 μm.

Fig. A16. Witchelina Magnesite, Sample 3741: Composition of recrystallised matrix (S1, S3, S4) and organic inclusions (characterised by high sulphur and chlorine) (S2, S8) (Plate 29).
TERMINATION HILL
Two samples were examined, both from outcrop in creek section and selected during the bulk sampling program in April 1997.

3725: Massive, very pale grey, extremely fine-grained, bedded magnesite with minor inclusions of randomly orientated dark grey to black albite crystals to 1.5 mm length. SEM examination of a freshly fractured surface.

3740: Magnesite conglomerate with very pale grey clasts, 2 mm to >20 mm across, in pale to dark grey, fine to medium-grained matrix. Both clasts and matrix cut by minor carbonate veinlets. SEM examination of a freshly fractured surface.
Plate 30: Termination Hill Magnesite, Sample 3725: Pale grey, fine-grained, bedded magnesite with black albite crystals and thin carbonate veins. Photo no. 3725a, sample width 15 mm.

Plate 31: Termination Hill Magnesite, Sample 3725: Sodium feldspar (albite) crystal (S1), 250x400 μm size, in fine-grained magnesite. Photo no. 25-3641, scale bar 100 μm.
Plate 32: *Termination Hill Magnesite, Sample 3725*: Sodium feldspar (albite) crystal (S4), in fine-grained magnesite. Photo no. 25-3641, scale bar 200 µm.

![Image of fine-grained magnesite with Albite crystal (S4)](image)

Fig. A17. *Termination Hill Magnesite, Sample 3725*: EDX spectra of albite crystals in fine-grained magnesite (see Plates 31 & 32). Presence of dolomite in S4 may indicate some later stage replacement of earlier formed albite.
Plate 33: Termination Hill Magnesite, Sample 3725: Thin dolomite vein, centre, cuts at right angles across magnesite bedding which varies in composition from dolomite (S5) to magnesite (S6). Thin dark bands, visible in Plate 30, are more dolomitic (and organic?). Photo no. 25-3653, scale bar 400 µm.

Fig. A18. Termination Hill Magnesite, Sample 3725: Composition of dark and light bands in bedded magnesite. Dark bands are dolomitic and the presence of P, S & Cl suggest some organic matter. Light bands are magnesite with some silica and calcium. (see Plates 30 & 33).
Plate 34: Termination Hill Magnesite, Sample 3740: Coarse magnesite conglomerate with large clasts of fine-grained magnesite in a matrix of magnesite and dark grey dolomite. Composition of clast S1 is predominantly magnesite with traces of Si and Ca (Fig. A19) Photo no. 3740a, sample width 18 mm.

Fig. A19. Termination Hill Magnesite, Sample 3740: Average composition of magnesite clast (S1) showing traces of silica and calcium (Plate 34).
Plate 35: *Termination Hill Magnesite, Sample 3740*: Detail of magnesite particles 1-5 µm across. Photo no. 40-3673, scale bar 4 µm.

Plate 36: *Termination Hill Magnesite, Sample 3740*: Recrystallised magnesite grain 100 µm across in fine-grained magnesite. Photo no. 40-3674, scale bar 40 µm.
**Plate 37:** Termination Hill Magnesite, Sample 3740: Matrix zone between magnesite clasts comprising mainly fine-grained magnesite (S7) with dolomitic patches (S4). Thin cross-cutting vein is largely Mg-calcite (S5) with segments of magnesite (S6) and rare quartz grain (S2). Photo no. 40-3675, scale bar 200 µm.

**Fig. A20.** Termination Hill Magnesite, Sample 3740: EDX spectra of magnesite (S7), dolomitic patches (S4), vein material (S5, S6) and quartz grain (S2) (Plate 37).
MYRTLE SPRINGS
Two samples were examined, one from bedded magnesite in the quarry face and the other from the crushed lump ore stockpile.

3658: Coarse magnesite conglomerate comprising rounded magnesite pebble clasts in a matrix of coarse sandy magnesite. SEM of a freshly fractured surface focused on a single clast with cross cutting thin carbonate veinlets.

3723: Massive, coarse, pale grey, poorly sorted magnesite pebble conglomerate comprising rounded, elongate 10 to 50 mm sized clasts of very fine-grained magnesite in a coarse sandy to fine granule magnesite matrix with carbonate cement. Minor cross cutting veinlets of pale grey carbonate are present. SEM examination of sawn face.
Plate 38: Myrtle Springs Magnesite, Sample 3658: Fine-grained magnesite with inclusions of talc flakes and cut by recrystallised carbonate vein. Photo no. 58-3562, scale bar 100 µm.

Plate 39: Myrtle Springs Magnesite, Sample 3658: Detail of Plate 38 showing distribution of talc flakes in magnesite and variation in the composition of the carbonate vein (right). Photo no. 58-3562, scale bar 40 µm.
Fig. A21: Myrtle Springs Magnesite, Sample 3658: Variation in composition of recrystallised vein material where darker grains are magnesite with traces of Ca and Fe (S1) and lighter grains are Mg-calcite with some Sr substituting for Ca (S2, S3, S4) (Plate 39).
Plate 40: Myrtle Springs Magnesite, Sample 3658: Detail of magnesite particles to 5 μm across (S6), together with coarser flakes of talc (S5). Photo no. 58-3564, scale bar 10 μm.

Fig. A22: Myrtle Springs Magnesite, Sample 3658: Composition of talc (S5) associated with fine-grained magnesite (S6) (Plate 40).
Plate 41: *Myrtle Springs Magnesite, Sample 3723*: Sawn surface of a coarse magnesite conglomerate showing areas examined: 23-3633 interior of a coarse clast; 23-3635 area of finer clasts with dolomitic matrix. Photo no. 23-3634, scale bar 1 mm.

Plate 42: *Myrtle Springs Magnesite, Sample 3723*: Detail of interior of a coarse magnesite clast comprising fine-grained magnesite (S3) with clusters of talc flakes (S2) and dolomitic patches (S1). Photo no. 23-3633, scale bar 40 μm.
Fig. A23: Myrtle Springs Magnesite, Sample 3658: Composition of mineral phases present in a coarse magnesite clast (Plate 42).
Plate 43: *Myrtle Springs Magnesite, Sample 3723*: Irregular-shaped, subangular magnesite clasts (mid-grey) in a matrix of Mg-calcite, talc (light grey) and magnesite. Photo no. 23-3635, scale bar 400 µm.

Plate 44: *Myrtle Springs Magnesite, Sample 3723*: Detail of Plate 43 showing fine-grained magnesite (S7) with patches of talc (S4, S6) and Mg-calcite (S5). Photo no. 23-3636, scale bar 20 µm.
Fig. A24: *Myrtle Springs Magnesite, Sample 3723:* Composition of mineral phases present in matrix around coarse magnesite clasts (Plates 43 & 44).
MOUNT HUTTON

Four samples were examined, all selected from the bulk sample taken from creek outcrop during the sampling program in April 1997.

3717: Weathered, white, coarse grained magnesite sandstone comprising white to pale grey, rounded, subspherical magnesite clasts in a white carbonate matrix. SEM of a freshly fractured surface.

3718: Sample as for 3717. SEM of a sawn face.

3719: Massive, coarse sand to fine pebble magnesite conglomerate comprising rounded magnesite clasts 1 to 5 mm diameter in a recrystallised carbonate cement. Colour varies from white to dark grey in streaky patches that cut across individual clasts. Other clasts are pale grey surrounded by white matrix. The rock has a distinct mottled texture and shows evidence of graded bedding. SEM of freshly fractured surface.

3720: Pale grey, magnesite pebble conglomerate comprising rounded, oval, fine-grained magnesite clasts 1 to 10 mm across in a matrix of slightly darker grey recrystallised carbonate matrix. Minor thin irregular crystalline carbonate veinlets cut across clasts and matrix. SEM of a sawn face.
Plate 45: Mount Hutton Magnesite, Sample 3717: Coarse magnesite sand comprising 1-2 mm detrital magnesite in a carbonate matrix. Sample appears white and moderately weathered. Photo no. 17-3592, scale bar 1 mm.

Plate 46: Mount Hutton Magnesite, Sample 3717: Detail of Plate 45 showing subrounded magnesite grains (S1, S2) with talc flakes (S5) in an open matrix that includes areas of high calcium content (S4). Photo no. 17-3593, scale bar 200 µm.
Fig. A25: Mount Hutton Magnesite, Sample 3717: Composition of magnesite grains (S1, S2), calcite matrix (S4) and possible talc flakes (Plate 46).
**Plate 47:** *Mount Hutton Magnesite, Sample 3717:* Detail of Plate 46 showing fine-grained magnesite (S11) with coarse talc flakes to >100 µm (S6) in an open matrix of recrystallised matrix of dolomite (S7, S8) and calcite (S9). Open texture in matrix is due to weathering. Photo no. 17-3594, scale bar 40 µm.

**Plate 48:** *Mount Hutton Magnesite, Sample 3717:* Detail of Plate 47 showing open fractures dolomite and void space in calcite matrix caused by partial dissolution and disruption during weathering. Photo no. 17-3595, scale bar 20 µm.
Fig. A26: Mount Hutton Magnesite, Sample 3717: Probable talc flakes (S6) with low Mg possibly due to preferential absorption of Mg X-rays resulting from sample position relative to the X-ray detector. Similarly, matrix composition is probably dolomitic (S7, S8) with some finer grained vugly calcite (S9). Fine-grained magnesite, typical of the sand-sized clasts, contains a trace of silica and calcium (S11). For location of sites analysed refer Plate 47.
Plate 49: Mount Hutton Magnesite, Sample 3718: Rounded, coarse sandy magnesite clasts in a carbonate matrix, sawn sample face. Photo no. 3718a, sample width 12 mm.

Fig. A27: Mount Hutton Magnesite, Sample 3718: EDX spectra of the centre of a coarse magnesite clast (S1) and the matrix between clasts (S2) (see Plate 49).
Plate 50: *Mount Hutton Magnesite, Sample 3718*: Detail of Plate 49 showing matrix between magnesite clasts to comprise mainly talc flakes and fine-grained magnesite. Photo no. 18-3602, scale bar 20 µm.

Fig. A28: *Mount Hutton Magnesite, Sample 3718*: EDX spectra of talc flakes (S7, S8) and fine-grained magnesite (S10) in the matrix (see Plate 50).
Plate 51: *Mount Hutton Magnesite, Sample 3719*: Massive coarse sandy to pebbly magnesite with distinct colour mottling from dark grey (centre) to pale grey to white. Analyses S1-S3 record the magnesite composition in different coloured areas, S4 on a grain margin shows the presence of talc and iron oxide with magnesite (see Fig. A29). Photo no. 3719a, Sample width 10 mm.

Fig. A29: *Mount Hutton Magnesite, Sample 3719*: EDX spectra of individual magnesite clasts in areas of white (S1), dark grey (S2) and pale grey (S3) mottling. Results confirm that magnesite composition is consistent across colour variation. Some talc and rare Fe oxide present in matrix (S4) (see Plate 51).
Plate 52: *Mount Hutton Magnesite, Sample 3720:* Magnesite pebble conglomerate cut by a thin carbonate veinlet (lower centre), sawn face. Enlargements focus on clasts and matrix (20-3611) and composition of the vein and adjacent clast (20-3614). Photo no. 3720b, Sample width 16 mm.

Plate 53: *Mount Hutton Magnesite, Sample 3720:* Backscattered electron micrograph highlighting the difference in composition between areas of pale matrix comprising mainly dolomite with minor talc and the darker grey magnesite in clasts and matrix. Photo no. 20-3611, scale bar 1 mm.
Plate 54: Mount Hutton Magnesite, Sample 3720: Detail of Plate 52 showing the intersection of two carbonate veinlets which cut through the centre of a large magnesite pebble clast. Photo no. 20-3614, scale bar 40 µm.

Plate 55: Mount Hutton Magnesite, Sample 3720: Enlargement of Plate 54 showing sites probe to determine differences in composition between the recrystallised magnesite vein and fine-grained magnesite of the pebble clast. Photo no. 20-3616, scale bar 20 µm.
Fig. A30: *Mount Hutton Magnesite, Sample 3720*: Comparison of the composition of recrystallised vein magnesite (S9) and fine-grained magnesite (S10) in the pebble clasts. Si and Ca are ubiquitous in original clasts but not in recrystallised magnesite. For location of probed sites refer Plate 55.