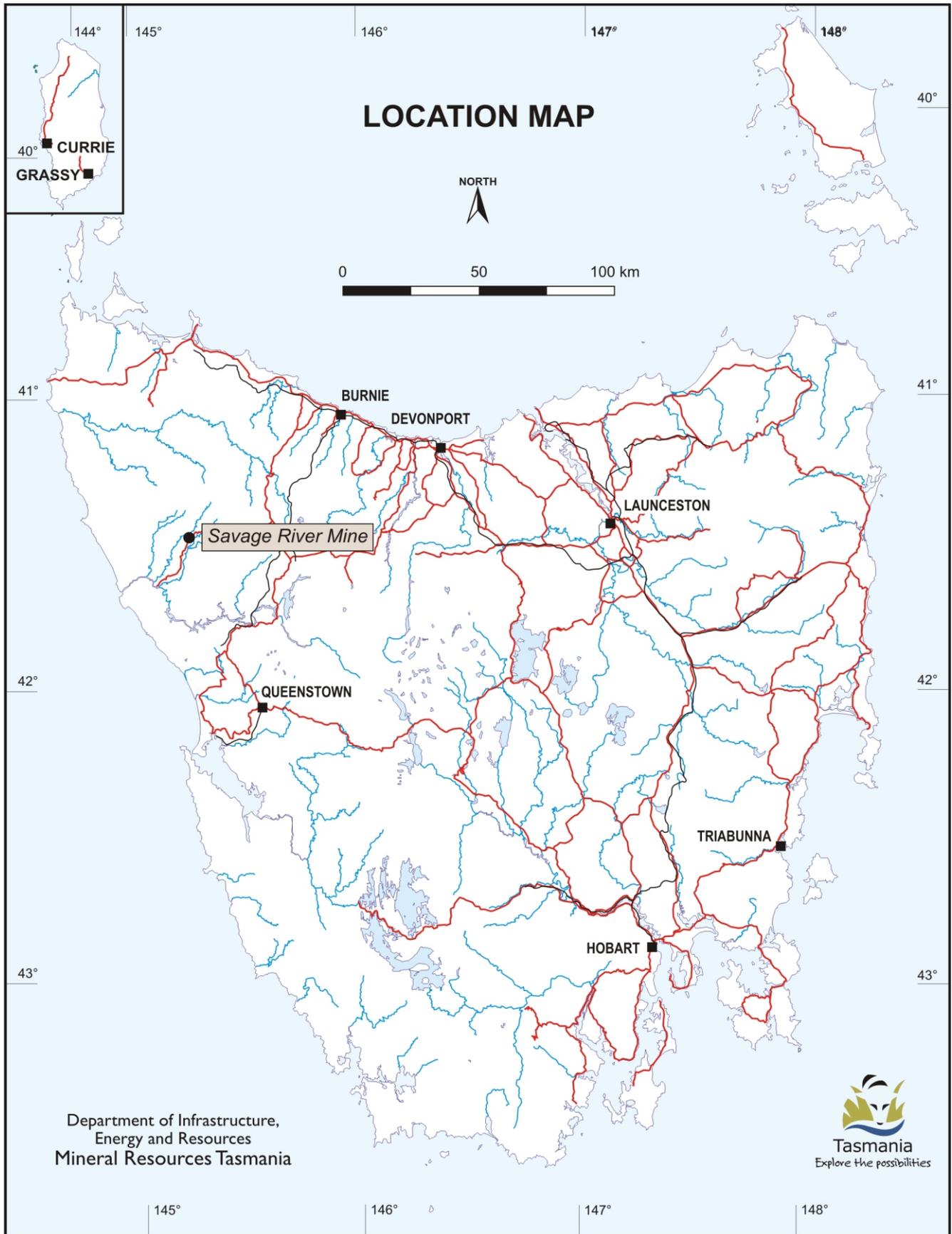


**Tasmanian Geological Survey**  
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**Petrology of the host rocks,  
including mineralisation and  
adjacent rock sequences,  
from the Savage River mine**

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## Contents

<b>Abstract</b> .....	5
<b>Introduction</b> .....	7
<b>Stratigraphy</b> .....	9
General classification of the Bowry Formation lithologies .....	9
<i>Mafic rocks</i> .....	9
<i>Feldspathic rocks</i> .....	10
<i>Magnesian ('ultramafic') rocks</i> .....	10
<i>Mineralisation</i> .....	10
<b>Petrographic summaries</b> .....	11
Western Ahrberg Group (AG) .....	11
Eastern Ahrberg Group .....	12
<i>Fulford Creek Schist</i> .....	12
Bowry Formation .....	13
<i>Mega Ramp Schist (MR)</i> .....	13
Mega Ramp muscovite schist (MRU) .....	14
<i>Western Wall Banded schist</i> .....	15
Albitite (fine grained) (W1) .....	15
Albitite, coarse grained (W2) .....	16
Western Wall Mafics (W3) .....	17
Quartzite (W4) .....	18
Quartz-amphibolite/pyroxenite (W5) .....	19
<i>Main Host Sequence (H)</i> .....	20
Amphibolite and pyroxenite (H1) .....	20
Mineralised units .....	21
<i>Ore (undifferentiated) (H2)</i> .....	21
<i>Pyrite rich-rocks (H2p)</i> .....	21
<i>Apatite rich-rocks (H2ap)</i> .....	23
Serpentinite (H3) .....	24
Silicate-dolomite rocks (H4) .....	25
Dolostone (H5) .....	26
Magnesite-stone (H6) .....	27
Mafic meta-volcaniclastic rocks (H7) .....	28
<i>Eastern Wall Mafic Sequence (EW)</i> .....	29
Eastern Wall carbonate-rich zones (EWC) .....	30
<i>Armstrong Creek Mafic schist (AC)</i> .....	31
Oonah Formation (OO) .....	32
Intrusive rocks (metadolerite) (ID) .....	33
Mylonite (Y) .....	34
Brecciated Fault Material (Yb) .....	35
<i>Quartz-rich breccia (Ybq)</i> .....	35
Veins (V) .....	36
<b>Discussion and summary</b> .....	38
Rock types .....	38
Mineralisation and alteration .....	39
<b>Conclusions</b> .....	41
Further work. ....	41
Acknowledgements .....	41
<b>References</b> .....	42

## Appendices

1. Sample locations, summarised details and list of abbreviations	55
2. Sample processing summary	61
3. XRD analyses	68
4. Drill logs, holes NDDH601 and LPDDH 0707	71
5. Petrographic summary	73
6. Petrographic statistics	81
7. Field photos, hand specimen photos and photomicrographs	85
8. ABM codes	113
9. Samples used for Figure 9	114

## Figures

1. Regional Map, NW Tasmania (From Turner & Bottrill, 2003)	6
2. Geology map of Savage River mine region, with sample sites	46
3. Sampling sites and geology, north of North Pit	47
4. Sampling sites and geology, North Pit	48
5. Sampling sites and geology, South Lens/Savage River Gorge East	49
6. Sampling sites and geology, Centre Pit/Savage River Gorge West	50
7. Sampling sites and geology, South Pit	51
8. Mineralogical Variation, drillhole NDDH601	52
9. Mineralogical Variation, South Pit Cross-Section	53
10. Time Space Diagram for the Savage River district	54

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## **Abstract**

The Proterozoic sequences in the Savage River mine area consist of metamorphic rocks showing very high variability in metamorphic grade and mineral assemblages. The main rock types observed in the field are mafic schist and hornfels or granulite, but also include albitite, quartzite, muscovite chlorite schist, dolomite and magnesite-rich carbonate rocks and magnesian skarn. Characteristically, many parts of the sequences are highly mixed, and interbanded carbonate-mafic rocks are very common. The main mineralisation identified is massive magnetite-rich bodies, but locally there are some small pyrite and apatite-rich zones, mostly associated with magnetite mineralisation, and minor weak copper mineralisation and some minor mineralised veins. All these rocks are moderately to highly metamorphosed and metasomatically altered but remnant original sedimentary and igneous textures can still be observed in some more competent rocks. Many of the mafic rocks have clastic textures suggesting they were originally basaltic volcanoclastic rocks or lithic arenites. Definite igneous rocks, including metadolerite and possibly minor metabasalt, have also been identified, the latter tentatively. Dolomite and magnesite-rich carbonate rocks have siliceous and mafic-rich variants, and are locally partly to totally altered and/or retrogressed into magnesian and calc-silicate skarns (including amphibolite, serpentinite and rarely pyroxene granulite).

Several metamorphic events can be identified in most parts of the sequences, including (paragenetically):

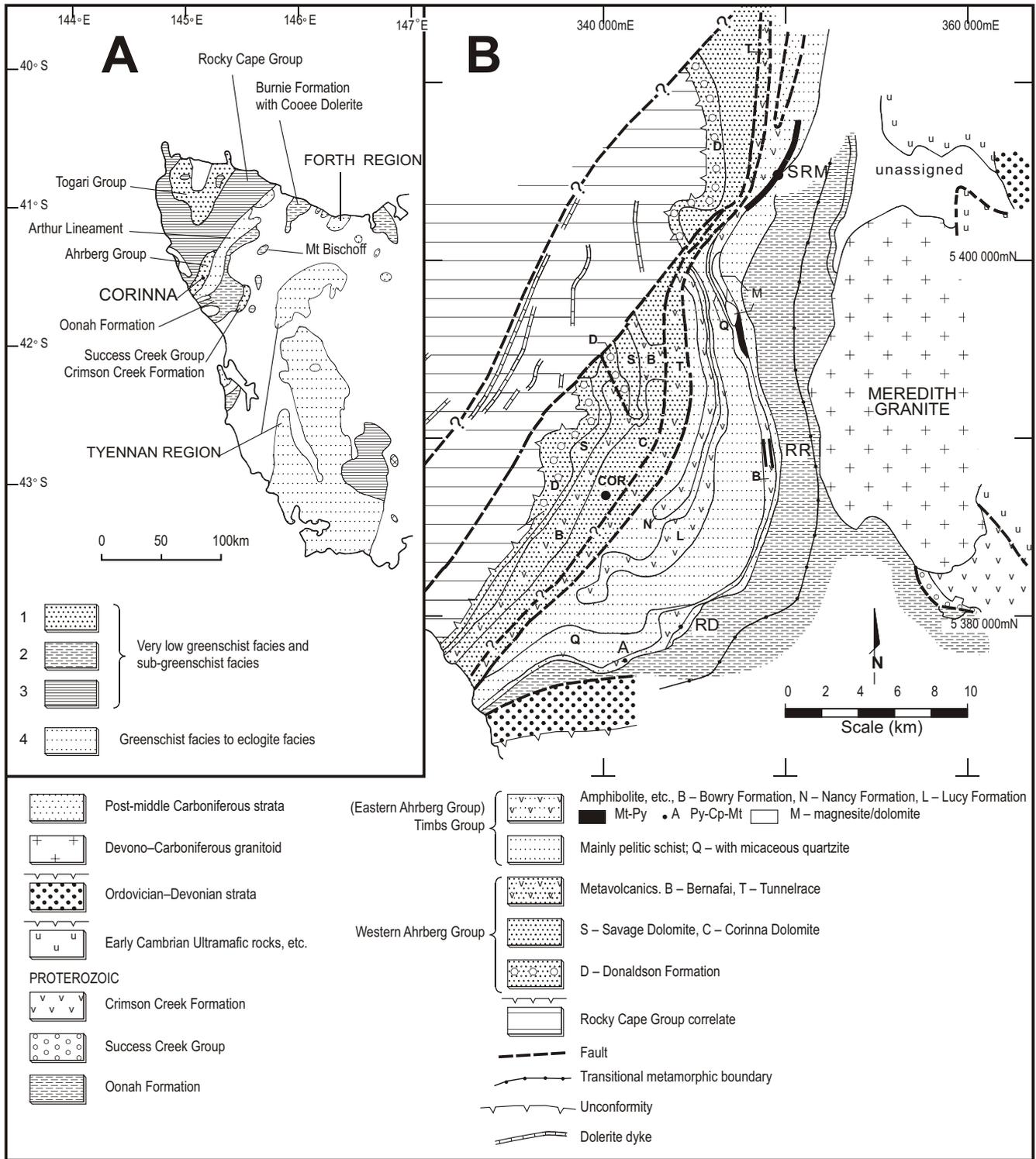
- (a) an early granulite to hornfelsic facies metamorphism;
- (b) a later blueschist facies, weakly penetrative deformation, with some veining;
- (c) at least two greenschist facies, penetrative events probably grading into mylonite; and
- (d) several late, weak retrogressive events, associated with unfoliated fault breccias and veins.

The absolute timing of these events is highly conjectural. The host rocks are all locally overprinted with multiple-stage and mineralogically complex veins, fault breccias and mylonites, but this appears to be concentrated in the mixed carbonate-mafic units. Hydrothermal alteration is mainly characterised by the occurrence of secondary carbonate, albite, epidote, albite, tourmaline and chlorite-rich zones and veins. Tourmalinisation and albitisation are concentrated in the sequences west of the main mineralised host zone, but their genetic relationships are uncertain.

The main ore mineralogy is very simple and consists of coarse-grained magnetite (the main ore) and pyrite with minor fine-grained hematite and chalcopyrite, plus some sporadic, coarse-grained apatite pods. These ore minerals are mostly disseminated to locally massive, or in minor veins. Late, relatively undeformed, vein and breccia mineralisation is common but volumetrically minor and low in grade; it mostly includes pyrite, hematite and chalcopyrite, and rarely magnetite, plus a wide range of gangue minerals, mostly related to the local host rocks. Texturally, the ore minerals appear to be largely of replacive origin throughout various rock types, but mostly occur within large-scale breccia and mylonite zones dominated by early carbonates and retrogressive Mg silicates. The ores generally appear to be relatively early, but the timing and origin are still under investigation.

The main magnetite mineralisation event was probably a high temperature metasomatism involving magnetite-pyrite replacement of early diagenetic magnesite and dolomite to form pyroxene olivine serpentine amphibole biotite skarn. Part of the mineralisation (mostly lower grade material) was hosted in intercalated mafic volcanoclastic rocks with intrusive dolerite bodies and possible basaltic lavas. The ore and surrounding rocks have subsequently undergone multiple deformational and metamorphic events, including a high pressure-low temperature blueschist facies event followed by retrogression to lower greenschist facies. The metasomatic events in the mine area include minor, but widespread, tourmalinisation and major albitisation restricted to the western sequence, and potassic and magnesian alteration in the host sequence. At this stage the relationship of these events to magnetite formation is unclear and under further investigation.

This report is the most systematic and detailed interpretative petrological study of all the main rock types throughout the mine to date, and points towards the magnetite ore being hosted by a highly metamorphosed and altered Mg-rich carbonate and mafic volcanoclastic-rich sedimentary sequence and was probably formed by pre or syn-metamorphic replacement of the host rocks. The mineralisation, setting and alteration are highly indicative of iron oxide-copper-gold styles of mineralisation, particularly the Kiruna and Iron-skarn subtypes, but the genesis is under more detailed investigation.



The Savage River iron mine (SRM) consists of a number of large to very large open-cut workings in northwest Tasmania, based on a group of magnetite-rich lenses irregularly distributed within a series of highly metamorphosed magnesian rocks, including carbonate and mafic rocks. These rocks, which occur in the Arthur Metamorphic Complex (AMC) of probable late Proterozoic age, are currently being mined by Australian Bulk Minerals (ABM). The geology and mineralisation of the mine district, as for the AMC in general, is poorly understood; a review is given in Bottrill and Taheri (2006).

Previous petrological studies of rocks in the SRM have been conducted by several workers (summarised by Bottrill and Taheri, 2006), most particularly by Urquhart (1966), Spiller (1974), Green and Spiller (1977), Matzat (1984), Thornett (1999) and Bottrill (2006). Frost (1981) conducted detailed studies of the dolomites and magnesites in the Savage River mine area, and Spry (1964), Turner and Bottrill (2001) and Everard (2002) studied closely-related blueschists elsewhere in the AMC. The studies in this report were mostly based on the mapping and preliminary rock classifications of Thornett (1999) and Turner (2006).

This second report for this project is probably the most systematic petrographical study that has so far been undertaken of the Savage River deposits. A total of 325 rock samples were collected from the Savage River mine and near vicinity in 2005 to 2007 (locations are given in Appendix 1 and Figures 2 to 7) and about 290 of these were submitted for petrographic description and/or XRD analysis and interpretation (see the process summary in Appendix 2 and XRD results in Appendix 3). The samples were mostly from relatively fresh outcrops in the mines and the bed of the Savage River, and also from some ABM drill core (including Long Plains). Drill core logs are shown in Appendix 4. Two cross sections have been drawn across the ore body (one based on a drill hole) showing the mineralogical variation determined in the specimens sampled (fig. 8, 9).

Samples prepared for petrographic studies were mostly examined by transmitted and reflected polarised light and stereo-microscopic techniques, with considerable X-ray diffraction (XRD) backup, in the MRT laboratories at Rosny Park. The mineralogical contents were determined approximately using the above-mentioned techniques; these results were compiled and are shown in Appendix 5 and various tables throughout this report, largely for comparative statistical purposes (summarised in Appendix 6). Because of the high variability and low sample coverage, the detailed statistics would probably be unreliable for most minor rock types. The petrology is summarised for each major rock type or unit identified, with a summary of the interpreted relative age of some ore and other minerals. Most of the interpretations are made in the *Discussions and*

*Summary* section. The mineralogy is summarised for each rock type/unit. Field photographs, specimen photographs and photomicrographs are shown in Appendix 7.

These samples are also being subjected to whole-rock geochemical, stable isotope (silicate oxygen, sulfide sulfur, and carbon and oxygen from carbonates), radiometric age dating and electron microprobe studies to help elucidate the origin of both the ores and host rocks. A further 81 samples were collected along the Arthur Metamorphic Complex and from surrounding units, mostly in or associated with magnetite-rich deposits. These will be studied for comparative purposes with the Savage River mine samples by the same processes, and the results will be given in the third report for this project. This third report will also include our final interpretation of the likely genesis of the Savage River and related magnetite deposits in the district.

The rocks studied in this report were initially classified on the basis of their broad stratigraphic subdivision, as used by Thornett (1999), Turner (2006) and others in ABM reports and maps. The ABM coding system did not work satisfactorily for our studies, as it indicated only the general rock type, independent of position in the sequence. Our studies needed to indicate both stratigraphic units and rock types, so our own mixed stratigraphic and petrological-based system was developed.

Some of the ABM-defined units were subdivided further on the basis of their distinct mineralogical assemblages (see under the individual unit for these descriptions). It is recognised that there may be locally complete gradation between many of these sub-units, but these subdivisions were still useful where there appeared to be significant mineralogical or textural differences between extreme variants, with a probable genetic significance (e.g. variable alteration facies). This subdivision was done to enable better classification of our petrographic and geochemical analyses rather than to just define mappable units (although it may assist). Some units are very complex, with distinct variants (e.g. pyroxene-rich rocks) that have not been classified separately due to insufficient sampling for useful definition. The rock classifications used here, mostly listed and described in sequence from west to east, are shown in Table 1. Many of these are ABM-defined units but there are some significant variances:

1. The Box Cut carbonate assemblage and the magnesite unit in the Eastern Wall carbonate-mafic assemblage on ABM maps are considered indistinguishable by us, and probably represent zones with a concentration of massive, relatively unaltered magnesite and dolomite-rich bands, integral to the Main Host assemblage.

**Table 1**

*The main pre-Tertiary stratigraphic units and rock types identified in and around the Savage River mine by this study*

<i>Code</i>	<i>Stratigraphic/rock classification</i>	<i>Main rock type</i>
<b>AG</b>	<b>Western Ahrberg Group</b>	Quartz-chlorite schist
	<b>Eastern Ahrberg Group</b>	Pelitic schist and quartzite
FC	Fulford Creek Schist	Muscovite schist
<b>BF</b>	<b>Bowry Formation</b>	Metamafites
MR	Mega Ramp Schist	Quartz-albite-chlorite schist
MRU	<i>Muscovite schist zones</i>	Quartz-albite-muscovite-chlorite schist
W	Western Wall Banded Schist	
W1	<i>Albitite (fine grained)</i>	Albitite
W2	<i>Albitite (coarse grained, 'granite')</i>	Albitite
W3	<i>Western Wall Mafics</i>	Albite-amphibolite
W4	<i>Quartzite</i>	Quartzite
W5	<i>Quartz-amphibolite/pyroxenite</i>	Quartz-amphibolite or quartz-pyroxenite
H	Main Host assemblage	
H1	<i>Amphibolite and pyroxenite</i>	Amphibolite and/or pyroxenite
H2	<i>Ore (undifferentiated)</i>	Magnetite pyrite apatite silicates
H2	Magnetite ore	Magnetite pyrite, silicates
H2p	Pyrite-rich rocks	Pyrite magnetite, - silicates
H2ap	Apatite-rich rocks	Apatite magnetite, pyrite, silicates
H3	<i>Serpentinite</i>	Serpentinite, dolomite-serpentine rocks
H4	<i>Silicate-dolomite rocks</i>	Talc-chlorite-quartz-dolomite rocks
H5	<i>Dolostone</i>	Dolostone magnesite, talc, quartz
H6	<i>Magnesite-stone</i>	Magnesite-stone dolomite, quartz
H7	<i>Mafic meta-volcaniclastic rocks</i>	Chlorite-albite-amphibole-biotite-epidote schist
EW	Eastern Wall Mafic Sequence	Chlorite-albite-quartz amphibole schist
EWC	<i>Eastern Wall carbonate-rich zones</i>	Chlorite-albite-quartz-calcite schist
<b>AC</b>	<b>Armstrong Creek mafic schist</b>	Quartz-chlorite schist, quartzite
<b>OO</b>	<b>Oonah Formation</b>	Quartz-chlorite muscovite schist
<b>ID</b>	<b>Intrusive rocks (metadolerite)</b>	Chlorite albite epidote amphibole altered meta-dolerite
<b>Y</b>	<b>Mylonite</b>	Various
<b>Yb</b>	<b>Breccias</b>	Various
Ybq	Quartz breccia	Quartz carbonate etc.
<b>V</b>	<b>Veins</b>	Various?
Vq	Quartz veins	Quartz
Vn	Carbonate veins	Dolomite calcite
Vz	Mineralised veins	Magnetite pyrite hematite chalcopyrite
Va	Asbestos veins	

- The dolomite-chlorite-muscovite schist is considered to be the muscovite-rich schist in the Mega Ramp unit, rather than a part of the box-cut carbonate assemblage, as it appears relatively carbonate-poor where examined by us.
- The 'granitoid' of ABM maps is considered by us to be an intense albitite alteration facies of a probable metasediment.
- The 'Talc schist' on ABM maps is commonly talc-poor and mineralogically variable, but largely equates with our silicate-dolomite rocks.
- The Eastern Wall assemblages with banded carbonates were renamed the Eastern Wall Mafic Sequence with a carbonate-rich subdivision; ABM's 'Banded carbonate sequence' probably largely comprises lenses of magnesite ± dolomite in the adjacent host sequence mafic rocks.

The local stratigraphy and geological interpretations used by ABM are probably based mostly on the work of N. J. Turner (e.g. Turner *et al.*, 1991; Turner *et al.*, 1992; Turner and Bottrill, 2001; Turner, 2006), with some modification by Holm *et al.* (2003). The Cenozoic cover rocks are ignored in this report, and the basement rocks are all considered to be Proterozoic, although dating is sparse, the sequence is highly faulted and possibly partly allochthonous, and correlations are equivocal (Turner and Bottrill, 2001). A time-space diagram for the district is shown in Figure 10 and maps of the areas studied are shown in Figures 2 to 7. The Bowry Formation hosts the mine sequence and is the main focus of this study but some surrounding stratigraphic units are briefly described for comparison.

The Arthur Metamorphic Complex (or Arthur Lineament) is a highly metamorphosed fault-bounded belt running from near Somerset on the north coast, through Savage River and Corinna, to the west coast near Granville Harbour (fig. 1). It divides the weakly deformed Neoproterozoic Rocky Cape Group in the west from the time-equivalent Burnie and Oonah formations in the east, and includes the Bowry Formation and the eastern Ahrberg Group (Holm and Berry, 2002).

The oldest unit in the immediate district shown on ABM mine plans is probably the psammitic Oonah Formation, occurring east of the Bowry Formation (Holm *et al.*, 2003).

West of the Bowry Formation lies the Ahrberg Group, divided into fault-bounded eastern and western sectors by Holm and Berry (2002). The eastern sector was originally described as the Whyte Schist (Spry, 1964) and later renamed the Timbs Group, defined as containing pelitic schist and quartzite units in its lower parts and the Bowry Formation in the upper part (Turner *et al.*, 1991; Turner and Bottrill, 2001). Holm *et al.* (2003) noted that the Bowry Formation, although lithologically similar, was tectonically and metamorphically quite distinct from the Ahrberg Group, and is separated from it by a major fault. The Eastern Ahrberg Group (lower Timbs Group) is probably represented at Savage River by the poorly exposed, muscovite-rich, Fulford Creek Schist.

The Western Ahrberg Group (as described by Holm *et al.*, 2003) comprises mafic volcanic rocks. It is probably represented by the chloritic phyllite, slate and sandstone exposed in the area west of the Bowry Formation and Fulford Creek Schist, mapped by ABM as 'Ahrberg Group', dolomitic carbonate and siliciclastic sedimentary rocks. It is of somewhat lower metamorphic grade than the Bowry Formation.

The Bowry Formation (hosting the magnetite ores) lies to the west of this formation, probably with a fault contact (Turner and Bottrill, 2001) and has been tentatively subdivided (from west to east) by Turner

(2006) into the Mega Ramp Schist, the Western Wall Banded Schist, the Main Host Assemblage, the Eastern Wall Assemblage and the Armstrong Creek Schist. The Bowry Formation is possibly a correlate of the Neoproterozoic Togari Group, especially the Kanunnah Subgroup, which is also dominated by mafic lavas, sedimentary carbonate rocks and mafic greywackes in the Smithton basin (Turner *et al.*, 1992; Turner and Bottrill, 2001; Everard *et al.*, 2007). It may also correlate with the Crimson Creek Formation and Cleveland-Waratah sequences to the east and south, based on similar lithologies and igneous geochemistry (Crawford and Berry, 1992). Holm *et al.* (2003) considered the Bowry Formation to pre-date these other sequences, given a 778 Ma date determined for a deformed granitic enclave, a possible dyke.

Holm *et al.* (2003) noted the presence of a relatively narrow stratigraphic unit resembling the Ahrberg Group, and described as the Ahrberg Group Correlate, east of the Bowry Formation. This may correlate with the Armstrong Creek Schist, although it is included in the Bowry Formation on ABM mapping, and will be considered as such in this report. It is quite variable in lithology and metamorphic grade.

## **General classification of the Bowry Formation lithologies**

Rocks within this formation are highly variable and were broadly subdivided by Thornett (1999) and Turner (2006) for internal ABM mine mapping and drill logging purposes, mostly for ore definition and engineering purposes rather than stratigraphy. These ABM units have a large mineralogical heterogeneity, due in large part to overprinting by varying styles and degrees of alteration and mineralisation, plus some variability in metamorphic facies (due mostly to variable degrees of retrogression). Some subtypes to the main units could be defined mineralogically (Table 1) and these are described in the following petrology section, while more general comments follow below. The mineralogical distribution within each of these new subunits may still be highly heterogeneous, for the above reasons, as well as original sedimentary variability.

### **Mafic rocks**

Metamorphosed mafic rocks are widely distributed in the Bowry Formation (mostly in lithologies AG, W3, H7, EW, AC and ID, Table 1) but are difficult to categorise precisely as they are all at least moderately altered and metamorphosed, and many are highly affected by brecciation, veining and mylonitisation. They were mostly classified by Thornett (1999) as metagabbro and metadolerite.

Dolerite, the main pre-metamorphic mafic igneous rock identified here, was characterised in this study as an intrusive by:

- A relatively homogeneous, unlaminated groundmass texture, with little or no foliation;
- A medium grainsize in relict primary mineral textures, from about 1 to 5 mm;
- Showing lath-like plagioclase crystals in a mafic groundmass (possible subophitic texture) and/or a relict porphyritic (plagioclase-phyric) texture;
- The lack of muscovite or other sedimentary minerals;
- Their generally relatively small and very discontinuous nature; and
- Some intrusive relationships (despite some possible amygdular structures in the same bodies).

Some bodies may be highly boudinaged basalt lavas, but no definite pillow lavas could be identified.

Mafic volcanoclastic rocks (basaltic tuff or volcanolithic sandstone and siltstone?) are very common throughout the sequence and are tentatively identified by a diffuse, non-mylonitic banding and an homogenous clastic nature (with clasts ~0.1–1 mm diameter), highlighted by shard-like leucoxene aggregates. The clasts commonly contain rounded or irregular albite and amphibole crystals, and mostly lack significant quartz. These rocks may be immature mafic sandstone, very similar but less metamorphosed than those in the Keppel Creek Formation in the Smithton Basin (Everard *et al.*, 2007), but the homogeneity and lack of detrital quartz, micas, etc. is suggestive of a tuffaceous origin. Wilson (1991) also considered that some similar laminated chloritic rocks in the Bowry Formation near the Pieman River were probably originally mafic volcanoclastic rocks.

Similar granular/clastic mafic rocks that additionally contain biotite muscovite, and sometimes rounded to ovoid quartz grains and sparse zircon, are considered to be largely mafic-derived sandstones, probably greywacke or lithic wacke. These are called metamafic sandstone in this report for simplicity.

The rocks described from the Savage River mine as schist and phyllite are probably mostly metasediments, but may include metadolerite, meta-tuff and possibly some highly altered metabasalt.

### Feldspathic rocks

The feldspar-rich rocks identified in the mine were described by Thornett (1999) as mylonites, altered mafic rocks, and tonalite. In this report they are mostly classified as albitites, an alteration rock type, even when they contain significant quartz, chlorite and/or amphibole (W1, W2; Table 1). This classification is used here because the rocks mostly have no definite igneous textures or minerals, mylonitic textures are

equivocal, and they may possibly even show some relict sedimentary layering and detrital minerals (e.g. rounded tourmaline) and appear to grade into quartzitic rocks and possible skarns.

Some albitites are relatively coarse grained and possibly cross-cut other lithologies, and are shown as 'granites' on some maps, but are still mostly albite-dominant, very quartz-poor and lack detectable K-spar. These are tentatively described here as 'coarse grained albitite', as they have little consistent compositional difference to the other finer albitites, other than containing less mafic and more late-stage carbonate-hematite alteration. Their field relationships are quite equivocal; these coarser zones may have dyke-like features cross-cutting more mafic albititic units, but the boundaries are commonly diffuse and veining, mylonitisation, brecciation and alteration is pervasive in these zones.

The petrography of all the albititic rocks is most consistent with a sedimentary replacement origin, although there could be an original igneous component in some zones.

### Magnesian ('ultramafic') rocks

These include serpentine, talc and pyroxene-rich rocks and probably most of the amphibolites in these rocks (H1, H3, H4, H5, H6; Table 1). They were described by Thornett (1999) as altered ultramafic rocks. In this report they are described principally as magnesian skarns, as they lack igneous affinities, are closely spatially associated with sedimentary dolostone and magnesite-stone, and appear to be generally Al, Ti, Ni and Cr-poor (from our preliminary geochemistry results). Chromite is absent and Ti-minerals are generally sparse, also suggestive of a carbonate replacement origin. The heat source for skarn formation is currently somewhat obscure. There is some complex intermixing of these magnesian rocks with mafic and other rock types, probably largely due to a combination of sedimentary intercalation, plus later tectonism, especially mylonitisation, giving some complex hybrid rocks.

### Mineralisation

The mineralised rocks at Savage River are defined, in accord with ABM standard classifications, as containing greater than 15% mineralisation, extended for this study to include sulfide minerals (pyrite and chalcopyrite), hematite and other related, possibly hydrothermal, minerals (including apatite), as well as magnetite (the most abundant ore mineral). Some subdivisions of mineralised units are described under their specific rock type, depending on the relative abundance of magnetite, apatite and pyrite (H2, H2p, H2ap; Table 1). Possible origins are varied and were summarised in Bottrill and Taheri (2006).

## Western Ahrberg Group (AG)

### Definition

This stratigraphic unit defines a Neoproterozoic volcano-sedimentary sequence overlying the Rocky Cape Group in northwestern Tasmania (Turner *et al.*, 1991, 1992; Turner and Bottrill, 2001; Holm and Berry, 2002). It is marked as Ahrberg Group on ABM maps but Holm and Berry (2002) renamed this unit to distinguish it from the Eastern Ahrberg Group, previously considered part of the Timbs Group.

The Western Ahrberg Group consists mostly of turbidite-deposited sandstone and conglomerate in the lower part (Donaldson Formation), some dolomite in the middle section (Savage and Corinna dolomites) and some metamaficite in the upper parts (the Tunnelrace and Bernafai metavolcanics; Turner and Bottrill, 2001). The samples examined in this report suggest that the unit could be subdivided lithologically, but there is insufficient sampling to do this at present.

**Main ABM codes:** OXC, SRW (see Appendix 8)

**Typical samples:** C109091, C109093

**Photographs:** C109093 (see Appendix 7)

### Distribution and field relationships

This unit comprises the western half of the AMC and crops out extensively from northwest of Savage River south to Granville Harbour. It is well exposed in the Savage River gorge, west of the mine (fig. 2).

### Hand specimen

The rock type is mostly a fine-grained, green-grey siltstone, slate or phyllite with an irregular to slaty foliation and no obvious mineralisation or veining.

### Petrography

The polished thin sections indicate that the rocks are composed mostly of green chlorite, with subdominant quartz, muscovite, sporadic subordinate to dominant albite, biotite, blue-green amphibole, yellowish epidote and carbonate minerals (calcite and/or dolomite), and minor to trace muscovite, tourmaline, pyrite and leucoxene. Plagioclase occurs in a fine-grained matrix and as medium-grained (up to 1.5 mm), irregular to rounded, sub-equant clasts (probably detrital grains).

Textures suggest that the rocks are mostly chloritic phyllite, possibly originally a mafic-derived mudstone, and one sample is a fine-grained lithic (mafic) sandstone or volcanoclastic rock. Some mafic clasts may have been lithic detrital grains. The matrix to these clasts consists mostly of fine-grained quartz plagioclase chlorite; it may be variably silicified. Trace tourmaline occurs sporadically, both disseminated in the matrix and in diffuse veinlets. There are minor quartz veinlets; these are pre- or syn-deformational, being recrystallised, contorted and boudinaged. The rock may be locally highly deformed, typically with a crenulated schistosity.

Magnetite was found in one sample (C109091) and very fine leucoxene is ubiquitous, but no pyrite or other ore minerals were observed. The magnetite (~8%), up to 0.2 mm, is euhedral to anhedral and is disseminated throughout the rock. Some coarser magnetite grains (up to 0.5 mm diameter) contain cores of chromite (indicating some ultramafic rocks in the sediment source).

The calcite, magnetite and tourmaline are probably mostly late (post-tectonic) replacement phases.

**Table 2**

*Mineralogy summary: AG*

Wt. %	Max.	Min.
Calcite	10	0
Quartz	15	10
K-feldspar	5	0
Albite	30	0
Epidote	5	0
Amphibole	15	0
Chlorite	65	25
Muscovite	15	0
Tourmaline	5	0
Magnetite	8	0

(3 samples examined)

### Rock type and genesis

The rock type is probably a metamorphosed mixed mafic-rich (tuffaceous?) mudstone/siltstone/sandstone sequence.

## Eastern Ahrberg Group

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### Definition

This stratigraphic unit defines a Neoproterozoic volcano-sedimentary sequence in the Arthur Metamorphic Complex, overlying the Western Ahrberg Group, and was previously known as the lower Timbs Group (Turner *et al.*, 1991, 1992; Turner and Bottrill, 2001; Holm and Berry, 2002). It consists mostly of pelitic schist, sporadic carbonate units (magnesite and dolomite-rich), tuffaceous and quartzitic sandstone, with some metamaafite (including the Lucy and Nancy formations, not recognised near the Savage River mine). It is dominated by amphibolite, mylonite, magnetite and pyrite-rich rocks, and Mg-rich carbonates. The Bowry Formation is lithologically similar but is distinguished on the basis of its higher metamorphic grade (up to blueschist facies), but its relationships are unclear (Turner and Bottrill, 2001; Holm and Berry, 2002). The Fulford Creek Schist is interpreted here as a part of Eastern Ahrberg Group and this is described briefly below.

**Main ABM code:** SXW?

### Distribution and field relationships

This unit comprises the eastern half of the AMC from northeast of Savage River southwest to Granville Harbour. It is poorly exposed in the Savage River mine area (fig. 2).

### Fulford Creek Schist

#### Definition

This is an informal unit name used on ABM mapping for a muscovite-bearing pelitic unit to the west of the mine sequence. It is probably a part of the Timbs Group, but is poorly defined.

**Main ABM code:** SXW

#### Distribution and field relationships

This unit occurs to the north and west of the Savage River North Pit (fig. 2, 3), but its extent is poorly defined. It is not well exposed in the areas investigated, being highly weathered in outcrop, and apparently not exposed in the mine workings or in any available drill core. No useful samples could be collected.

## Bowry Formation

### Definition

This stratigraphic unit defines a Neoproterozoic volcano-sedimentary sequence in the Arthur Metamorphic Complex in northwestern Tasmania (Turner *et al.*, 1991, 1992; Turner and Bottrill, 2001). It is defined largely on the basis of high metamorphic grade (to blueschist facies), but as the unit is fault-bounded its relationships and continuity are unclear (Turner and Bottrill, 2001). The Bowry Formation is dominated by amphibolite, mylonite, breccia, albitite, magnetite and pyrite-rich rocks and Mg-rich carbonates. It includes most of the rock units in the Savage River mine area, comprising the Mega Ramp Schist, the Western Wall Sequence, the Savage River Mine Host Sequence, the Eastern Wall Sequence and the Armstrong Creek Schist, all described individually below.

### Distribution and field relationships

This unit occurs along the eastern side of the AMC, probably from the north coast near Wynyard, south through Savage River to the west coast near Granville Harbour. It is best exposed in the Savage River mine (fig. 2).

## Mega Ramp Schist (MR)

### Definition

This stratigraphic unit is used informally by ABM geologists for some relatively unmineralised quartz-albite-chlorite muscovite schists, possibly related to the Fulford Creek Schist (unpublished ABM mapping). More micaceous sections of this unit can be separately classified as mica schist (see MRU below), but their continuity and mappability are uncertain.

**Main ABM Codes:** OXH, MXC

**Typical samples:** C109111, C108915

**Photographs:** C109115, C109111, C109109

### Distribution and field relationships

This unit occurs along the western side of the Savage River North and Central pits, extending to the north, and possibly cutting through the Fulford Creek Schist (fig. 2), but its extent and relationships are poorly defined. It is essentially intermediate in composition between the albitite (W1, W2, Table 1) and quartzite (W4, Table 1), but usually contains more chlorite and

micas, and lacks amphiboles. The Mega Ramp Schist may be a part of the Eastern Ahrberg Group rather than the Bowry Formation, and is best exposed in the western side of North Pit, although it is largely weathered.

### Hand specimen

The rock sample is a laminated, greyish rock with phyllitic texture, and no visible mineralisation.

### Petrography

The polished thin sections indicate that the rock type is composed mostly of fine-grained quartz and albite with minor chlorite and trace muscovite. There is also sporadic abundant dolomite and tourmaline, and traces of calcite, biotite, apatite and leucoxene. There is typically strong but contorted layering, brecciation and mylonitisation, and some late chlorite-carbonate-quartz-albite veins.

The only opaque minerals observed were traces of pyrite (up to 5%) and hematite (up to 1%).

The hematite, pyrite and tourmaline are probably mostly late replacement phases.

**Table 3**

*Mineralogy summary: MR*

Wt.%	Max.	Min.
Carbonate	10	0
Dolomite	30	0
Calcite	4	0
Quartz	65	15
K-Feldspar	5	0
Albite	60	10
Chlorite	15	1
Biotite	3	0
Muscovite	10	0
Tourmaline	15	0
Apatite	1	0
Leucoxene	2	0
Hematite	1	0
Pyrite	5	0

(15 samples examined)

### Rock type and genesis

This is a chlorite-muscovite-albite schist, probably representing a highly altered, brecciated and mylonitised mafic-rich metasediment, probably partly albitised and carbonate altered.

## ■ Mega Ramp Muscovite Schist (MRU)

### Definition

This rock type was defined here for some muscovite-rich schists (greater than 20% muscovite) near the western side of the Bowry Formation. It was mapped by ABM with the Mega Ramp Schist, but is separated here as it is petrologically and visually quite distinct and is possibly equivalent to the Fulford Creek Schist (possibly Eastern Ahrberg Group?).

**Main ABM Code:** OXH

**Typical samples:** C108889, C109144

**Photographs:** C108889, C109144

### Distribution and field relationships

This rock type was only noted within the Mega Ramp Schist zone mapped on the northwestern side of the Savage River North Pit (fig. 2-4). The unit is well exposed in this area, although it is largely weathered. It may grade into the Mega Ramp Schist and/or the Fulford Creek Schist.

### Hand specimen

The rock type is mostly a laminated, greyish rock with phyllitic to schistose texture, and no obvious mineralisation.

### Petrography

The polished thin sections indicate that this rock type is composed dominantly of fine to coarse-grained green chlorite, muscovite and albite with mostly only minor quartz. There is also locally abundant dolomite and green-brown biotite, and traces of needles of brown (schorl?) tourmaline, and fine leucoxene. Some albite grains (to about 0.2 mm) appear to be porphyroblastic,

and its inclusions preserve an earlier foliation, now variably rotated. The foliation wraps about the albite, and its textures indicate syn-metamorphic albitisation. The chlorite may form elongate grains to about 0.5 mm, at various angles to the foliation; these are probably pseudomorphs after primary biotite or an unidentified porphyroblastic mineral. There is typically a strong but contorted layering, plus brecciation and mylonitisation, and some common late-stage chlorite-dolomite-quartz-albite veins.

The only opaque mineral observed was traces of pyrite (up to 5%).

Dolomite, pyrite and tourmaline are probably mostly late (post-tectonic) replacement phases.

**Table 4**

*Mineralogy summary: MRU*

Wt. %	Max.	Min.
Dolomite	15	0
Quartz	20	0
Albite	30	15
Chlorite	25	0
Biotite	20	0
Muscovite	50	20
Tourmaline	0.5	0
Leucoxene	5	0
Pyrite	5	0

(4 samples examined)

### Rock type and genesis

This is a chlorite-muscovite-albite schist, probably representing a highly altered, brecciated and mylonitised pelitic and mafic-rich metasediment, probably partly albitised and locally carbonate altered.

## Western Wall Banded Schist

### Definition

This stratigraphic unit is used informally by ABM geologists for some relatively unmineralised and typically banded albite chlorite amphibole quartz schist and granulite along the western side of the Bowry Formation, and probably part of that unit.

**Main ABM code:** OXC

### Distribution and field relationships

This unit occurs along the western side of the Savage River North, Central and South pits (fig. 2-8), but its extent and relationships are poorly defined. It is well exposed and relatively massive in these areas, and is characterised by prominent banding, with felsic (albititic) to siliceous (quartzitic) and mafic layers. It may grade into the Mega Ramp Schist (MR) further north. The Western Wall Banded Schist has been mineralogically subdivided into normal albitite (W1), coarse-grained albitite (W2), and mafic (W3), quartzitic (W4) and quartz-amphibole pyroxene (W5) units.

### ■ Albitite (fine grained) (W1)

#### Definition

This rock type was defined here for relatively fine grained, albite-rich (greater than 50% albite) granulite, mylonite and schist, forming a major part of the Western Wall Banded Schist (unpublished ABM mapping). These rocks are mostly moderately rich in mafic minerals and/or micas, but some may be almost pure albite.

**Main ABM code:** ORF

**Typical samples:** C109135, C108846, C108898

**Photographs:** C108898, C108850, C108846

#### Distribution and field relationships

This rock type occurs along the western side of the Savage River North, Central and South pits (fig. 2-8), but its extent and relationships are poorly defined. It is well exposed and relatively massive in these areas, and is characterised by a banded, felsic nature. It may grade into quartzite (W4), mafic rocks (W3) and the Mega Ramp Schist (MR).

#### Hand specimen

The rock type is a massive to laminated, fine to medium-grained, pale green to deep pink or white rock with common boudinaged quartz hematite veining and brecciation, and minor visible mineralisation.

### Petrography

The polished thin section indicates that the rock is composed mostly of very fine to medium-grained albite, locally rich in quartz, carbonate minerals (dolomite calcite), pale green-blue amphiboles and green chlorite. Most of the albite is untwinned, characteristic of metamorphic albite. There is also commonly minor to trace colourless mica (muscovite?), green-brown mica (biotite), leucoxene (sphene), coarse apatite and fine to coarse blue-brown schorl tourmaline present, plus minor to trace ore minerals.

The layering is probably largely sedimentary, but a strong tectonic (mylonitic) foliation is also locally present. Some samples are texturally cherty (e.g. C108914), but this may be a mylonite recrystallisation phenomenon. There are some late carbonate albite amphibole chlorite veins.

There are commonly minor or trace opaque minerals, mostly comprising disseminated pyrite (up to ~10%) and magnetite (up to 5%), while there may locally be traces of hematite.

The dolomite, pyrite, hematite, magnetite and tourmaline are probably all mostly late (post-tectonic) replacement phases.

**Table 5**

*Mineralogy summary: W1*

Wt. %	Max.	Min.
Carbonate	10	0
Dolomite	15	0
Calcite	10	0
Quartz	10	0
K-Feldspar	5	0
Albite	95	50
Epidote	2	0
Amphibole	40	0
Chlorite	20	0
Biotite	10	0
Muscovite	10	0
Tourmaline	8	0
Apatite	1	0
Leucoxene	8	0
Magnetite	5	0
Hematite	5	0
Pyrite	10	0

(22 samples studied)

### Rock type and genesis

The albitite probably represents a highly albite-metasomatised and mylonitised sandstone sequence, including mafic tuffaceous rocks. It may be a more albitised version of the Mega Ramp Schist.

## ■ Albitite, coarse grained (W2)

### Definition

This rock type was defined here for some relatively coarse-grained or porphyroblastic albite-rich (greater than 50% albite, with grain size greater than 1 mm) granulite, mylonite and schist, forming a major part of the Western Wall Banded Schist (unpublished ABM mapping). These rocks are mostly poor in mafic minerals and micas.

**Main ABM code:** ORF

**Typical samples:** C108861, C108856

**Photographs:** C108861, C108857, C108856

### Distribution and field relationships

This rock type occurs along the western side of the Savage River Central and South pits (fig. 6, 7), in irregular, sometimes dyke-like to diffuse zones, probably locally cross-cutting and/or replacing finer-grained albitites (W1) and mafic rocks (W3), but its extent and relationships are not well defined. It is well exposed and relatively massive in the above areas, and is characterised by a non-banded, mafic-poor and coarse-grained felsic nature and pale pinkish colour, with hematite rather than pyrite. These features all help to readily distinguish this rock type in the field from other related rocks.

### Hand specimen

This is a massive to laminated, medium to coarse grained, pale green to deep pink or white rock with very common albite-quartz-carbonate-hematite brecciation and/or veining, commonly containing some local hematite mineralisation but lacking pyrite.

### Petrography

The polished thin sections indicate that the rock type is composed mostly of medium to coarse-grained albite, locally rich in quartz, dolomite and hematite. There is also commonly some minor to trace muscovite, green chlorite, pale green-blue amphiboles, leucoxene and trace brown tourmaline present, plus some trace opaque minerals.

The sections are commonly porphyroblastic, with tabular to irregular, simply twinned albite crystals to a few millimetres in grain size, in a finer, commonly mylonitic to fine-grained albite groundmass. Some albite porphyroblasts show myrmekitic rims with intergrown quartz (e.g. C108857), and some show

complex checkerboard twins (C108856). The myrmekite, albite twins and groundmass textures are all typical of recrystallised mylonite (blastomylonite, Spry, 1969). There is usually some late stage quartz carbonate albite veining present.

There is commonly minor to trace hematite (up to 8%), but in contrast to the W1 albitites this rock type lacks magnetite and pyrite.

The dolomite, hematite and tourmaline are probably all mostly late (post-tectonic) replacement phases; some quartz is also late.

**Table 6**

*Mineralogy summary: W2*

Wt. %	Max.	Min.
Carbonate	5	0
Dolomite	20	0
Quartz	40	0
Albite	90	50
Epidote	2	0
Amphibole	5	0
Chlorite	5	0
Biotite	3	0
Muscovite	5	0
Tourmaline	5	0
Leucoxene	3	0
Hematite	8	0

(6 samples studied)

### Rock type and genesis

This rock has been described by ABM geologists as 'granite', but it has no mineralogical or textural features of this rock type (it totally lacks k-feldspar, generally lacks abundant quartz, and is quite inhomogeneous), plus its intrusive relationships are equivocal. If the rock was originally granite, the original nature has been totally obscured by metamorphism, deformation and alteration. The mineralogy, texture and field relationships suggest that the rock is probably a highly albite-metasomatised rock type. It differs from normal albitites (W1) in being coarser grained, more siliceous and poorer in mafic minerals and contains hematite rather than pyrite. This rock type is most probably a late-stage hydrothermally altered (silicified, oxidised and carbonate altered) and recrystallised version of the normal albitite (W1), forming in late-stage breccia zones.

## ■ Western Wall Mafics (W3)

### Definition

This rock type was defined here for mafic-rich amphibolite, mylonite and schist, forming a major part of the Western Wall Banded Schist (unpublished ABM mapping). It is defined here as containing 30–70% mafic minerals, 20–60% albite and up to 20% carbonate minerals.

**Main ABM code:** MXA, MXC

**Typical samples:** C109119, C108834

**Photographs:** C108887, C108858

### Distribution and field relationships

These rocks occur along the western side of the Savage River Central and South pits (fig. 2–7), mostly interbanded with albitite, but their extent and relationships are poorly defined. They are readily distinguished in the field from albitite by their more mafic and less granular nature.

### Hand specimen

This rock type is mostly a fine to medium-grained, green-grey, massive to laminated rock with a weak to irregular phyllitic foliation, and no obvious mineralisation.

### Petrography

The polished thin sections indicate that the rocks are very variable in composition and texture, but are mostly composed of sub-equal amounts of green chlorite, albite, amphibole and epidote, with locally abundant biotite, quartz and K-feldspar, and may contain minor to trace muscovite, talc, calcite, tourmaline, magnetite, pyrite and leucoxene. One rock is a quartz-chlorite schist (C108834), another an albite-amphibolite (C108858). Albite occurs as medium-grained (up to 1.5 mm), irregular to rounded, sub-equant grains (possibly detrital grains?). Some clasts may have been lithic grains. The matrix to these clasts consists mostly of fine-grained quartz, plagioclase and chlorite, and may be variably silicified. Biotite occurs as sparse green-brown grains in the matrix. Trace tourmaline occurs both disseminated in the matrix and in veinlets. The carbonate (calcite by XRD) is disseminated in the matrix and in veinlets. There are traces of quartz, as fine-grained to cherty clasts in the groundmass and in veinlets. The amphibole is blue green (sodic) and is disseminated in

the rock and in veinlets. Some coarser epidote blebs may represent altered feldspar phenocrysts or vesicles.

The rock is relatively homogeneous and only weakly foliated, with veinlets of quartz, albite, epidote and coarse-grained brown tourmaline. These are pre-deformational, being recrystallised, contorted and boudinaged. The rock type is moderately to highly foliated, but the relict primary textures resemble volcanoclastic sandstone or tuff rather than an igneous rock.

The main ore minerals observed are almost ubiquitous trace anhedral pyrite (up to 2%; up to 0.2 mm), and magnetite (up to 3%; up to 0.2 mm), both occurring as disseminated grains and in veinlets. Traces of chalcopyrite are also common.

The calcite, pyrite, magnetite and tourmaline are probably all mostly late (post-tectonic) replacement phases.

**Table 7**

*Mineralogy summary: W3*

Wt. %	Max.	Min.
Carbonate	5	0
Calcite	5	0
Quartz	5	0
K-Feldspar	10	0
Albite	40	20
Epidote	20	1
Amphibole	40	20
Chlorite	30	5
Biotite	10	0
Leucoxene	5	0
Magnetite	3	0
Pyrite	2	0

(5 samples studied)

### Rock type and genesis

This is probably a metamafic sandstone (tuff?) sequence, and is very similar to the mafic lithologies in the eastern wall and ore zone (H7, see below). The varying mineralogy may be due to several factors including different types of hydrothermal alteration, variations in the degrees of metamorphism and retrogression, and local zones of tectonism and faulting. The biotite probably indicates some early potassic alteration, or perhaps some intermixed argillaceous sedimentary material.

## ■ Quartzite (W4)

### Definition

This rock type was defined here for some quartzite and quartz schist (defined here as having greater than 65% quartz, up to 25% amphibole) forming a major component in some parts of the Western Wall Banded Schist (unpublished ABM mapping).

**Main ABM code:** SQO

**Typical samples:** C109123, C108925

**Photographs:** C108886, C108834

### Distribution and field relationships

These rocks occur along the western side of the Savage River Central and South pits (fig. 2-7), but their extent and relationships are poorly defined. They are not always readily distinguished in the field from albitite; some are feldspathic and may grade into these rocks.

### Hand specimen

The rock type is mostly a fine to medium-grained, green-grey, massive to laminated granular rock, commonly with a weak to irregular phyllitic foliation in more pelitic layers, and no obvious mineralisation.

### Petrography

The polished thin section indicates that this rock type is composed mostly of fine to coarse-grained quartz, locally with subordinate chlorite, albite, tourmaline and/or amphibole. There is also sporadic minor to trace pyrite, apatite, carbonates, sphene, zircon, talc, muscovite/sericite and green-brown mica (biotite) present. There are some bands and discontinuous stringers of green amphiboles and/or chlorite. Tourmaline is mostly very fine grained and disseminated, commonly as intergranular masses of very fine, stubby prisms (up to 10  $\mu$ m, e.g. C108901), which appear to replace some intergranular material. Some sparse, coarser grains show euhedral overgrowths on probable detrital, rounded cores, sometimes tectonically fractured (e.g. C108901). The tourmaline is generally all dark coloured, commonly with colour zoning, and varies from dark blue to green

and brown, and is probably mostly schorl. The tourmaline cores are typically dark blue with brown overgrowths, and these textures and compositions require further study to determine any genetic information.

The layering is probably largely a tectonic (mylonitic) fabric but a relict sedimentary foliation may be present where there are some coarse micaceous and amphibolitic layers (e.g. C108959). There is some pressure solution of quartz, represented by elongated, rounded quartz grains (up to 1 mm) in a finer groundmass (blastomylonite; e.g. C108916). The quartz is largely highly stressed to finely polygonally recrystallised (e.g. C108901). Some is very fine grained and may represent recrystallised chert (e.g. C108886).

Opaque minerals include only minor to trace disseminated pyrite (up to 8%).

**Table 8**

*Mineralogy summary: W4*

Wt. %	Max.	Min.
Carbonate	5	0
Dolomite	10	0
Calcite	2	0
Quartz	95	70
Albite	20	0
Amphibole	15	0
Chlorite	20	0
Talc	5	0
Biotite	2	0
Muscovite	5	0
Tourmaline	15	0
Apatite	1	0
Leucoxene	1	0
Pyrite	8	0

(7 samples examined)

### Rock type and genesis

This rock is probably a metamorphosed and altered quartz arenite, grading into a sub-litharenite, with variable argillaceous and mafic tuffaceous components, and some local tourmalinisation.

## ■ Quartz-amphibolite/pyroxenite (W5)

### Definition

This rock type was defined for some essentially feldspar-free quartz-amphibolite rocks and a possibly related pyroxene-quartz-amphibole rock, forming a minor part of the Western Wall Banded Schist. Some were called gabbros in the field by ABM geologists, but are Si-rich and Cr, Ti and Al-poor, and thus are probably not igneous in origin (based only on some preliminary whole-rock geochemistry and electron microprobe work). The rock type is defined as having greater than 25% amphibole + pyroxene, up to 10% albite and 10–65% quartz.

**Main ABM code:** MXA

**Typical samples:** C108891, C108845a

**Photograph:** C108845

### Distribution and field relationships

These rocks occur in the western side of the Savage River Central and South pits (fig. 2–7), mostly interbanded with albitite, but their extent and relationships are poorly defined. The rock type may grade into quartzite (W4) with decreasing amphibole content. They are not readily distinguished in the field from other similar mafic-rich rocks, although they are probably genetically unrelated to them.

### Hand specimen

The rock samples are typically fine-grained, pale to mid-green rocks, with little foliation, and usually contain minor pyrite.

### Petrography

The polished thin section indicates that the rock type is mostly composed of medium to coarse-grained quartz and blue-green amphibole. It may grade into amphibolitic quartzite. One possible variant contains

abundant colourless pyroxene (C108845), and may be a less retrogressed version of the amphibole-rich rocks. There is sporadic minor epidote and sporadic trace albite, brown biotite, green chlorite, leucoxene, brown tourmaline and carbonate. The rock type is commonly inhomogeneous, coarsely banded and quartz veined.

The opaque minerals include traces of disseminated pyrite (up to 5%) and magnetite (up to 1%).

**Table 9**

*Mineralogy summary: W5*

Wt.%	Max.	Min.
Carbonate	5	0
Quartz	40	15
Albite	5	0
Epidote	10	0
Amphibole	55	15
Chlorite	5	0
Biotite	5	0
Tourmaline	4	0
Clinopyroxene	60	0
Leucoxene	5	0
Magnetite	1	0
Pyrite	5	0

(4 samples examined)

### Rock type and genesis

This is probably a metasomatised mafic volcanic rock, sediment or tuff, or possibly an impure dolomitic carbonate, metamorphosed to granulite facies and largely retrogressed and highly altered. Preliminary trace element geochemistry shows that the rock has relatively high Zr/Ti, indicating close similarities with the W4 quartzite (probably originally siliceous carbonate rocks), but this will be further discussed in our next report, using geochemical results still in preparation.

## Main Host Sequence (H)

### Definition

This stratigraphic unit is used informally by ABM geologists for the main mineralised part of the Bowry Formation, lying between the Eastern and Western sequences (unpublished ABM mapping). As well as hosting the magnetite ores, this unit is variably rich in Mg-rich lithologies, including carbonate, amphibole, pyroxene, chlorite, serpentine and talc-rich rocks.

**Main ABM code:** MRB

### Distribution and field relationships

This unit forms a major part of the Bowry Formation in the Savage River mine area, and in several other mineralised areas in the AMC. It is well exposed in the Savage River mine and where it is intersected by the Savage River (fig. 2-7). The unit includes the following lithologies or sub-units, described individually below:

- Amphibolite and pyroxenite (H1)
- Mineralised units (H2)
- Serpentinite (H3)
- Talc-chlorite-quartz-dolomite rocks (H4)
- Dolostones (H5)
- Magnesite (H6)
- Mafic metasedimentary rocks (H7)

## Amphibolite and pyroxenite (H1)

### Definition

This rock type was defined here for some weakly mineralised amphibole and/or pyroxene-rich rocks, forming a major part of the Host Sequence, and containing greater than 75% amphibole pyroxene, less than 10% feldspars, less than 10% quartz, and with mineralisation (magnetite + pyrite) less than 15%.

**Main ABM code:** UOA or SOA

**Typical samples:** C108845b, C109137

**Photograph:** C109131b

### Distribution and field relationships

This rock type is abundant in the Host Sequence in all the pits in the Savage River mine (fig. 2-7). It is usually found close to the ore and is not always readily distinguished in the field from other mafic rocks, unless there is a local coarse amphibolitic lineation.

### Hand specimen

These rocks are mostly fine-grained, pale green to grey, strongly fibrous to massive/unfoliated, usually with a diffuse foliation or lineation and minor zones of coarse-grained magnetite and pyrite.

## Petrography

The polished thin sections indicate that the rocks are composed mostly of pale green to colourless amphibole (tremolite-actinolite), with some diopside-rich zones (C109131b), and traces of chlorite, muscovite, calcite, quartz, albite and tourmaline. The amphiboles may include cores of an earlier green (actinolite?) to brown phase (possibly cummingtonite-grunerite; e.g. C108886) and a finer, secondary, green to colourless tremolite/actinolite-like amphibole that largely overgrows or replaces it (e.g. C109138a, C108868).

The pyroxenite (C109131b) is granoblastic and almost unfoliated, but the amphibolite commonly has a moderate to strong, but variable foliation.

The opaque minerals observed are sporadic disseminated pyrite (locally up to 10%) and magnetite (up to 5%). Only one sample (C108886) has abundant fine stringers of leucoxene (sphene?).

Some magnetite and pyrite appear paragenetically early, forming some granoblastic aggregates with pyroxene.

**Table 10**

*Mineralogy summary: H1*

Wt.%	Max.	Min.
Calcite	5	0
Quartz	5	0
Albite	5	0
Amphibole	90	40
Chlorite	10	0
Muscovite	5	0
Tourmaline	2	0
Clinopyroxene	55	0
Magnetite	8	0
Pyrite	10	0

(7 samples examined)

## Rock type and genesis

This rock type is probably mostly a metamorphosed and metasomatised calc-silicate or magnesian skarn, including diopside and retrograde amphibole skarn. There is generally no mineralogical or textural indication of an igneous origin to these rocks, and the general paucity of Al, Ti and Cr in preliminary geochemical studies supports a sedimentary origin. Field relationships also indicate a spatial relationship to carbonate rocks and serpentinite, rather than being intrusive. One sample has some anomalous geochemistry (high Ti, Al, P and Na; unpublished data), and this may be more likely a Ca-metasomatised mafic rock.

## ■ Mineralised units

### Ore (undifferentiated) (H2)

#### Definition

This classification was defined here for a group of mostly mineralised or otherwise hydrothermally altered rock types, with greater than 15% of combined magnetite, pyrite, hematite, apatite and chalcopryrite, within the Host Sequence. These rocks are mostly magnetite-rich but apatite and pyrite-dominant zones also exist, and are described separately below.

**Main ABM code:** ZOO, ZAS, etc.

**Typical samples:** C109164, C109130

**Photographs:** R0013341, R0013340, R0013339, R0013338, C108907a, C108907a, C108906)

#### Distribution and field relationships

This rock type is the major rock type within the mineralised parts of the Host Sequence in all studied parts of the Savage River mine (fig. 2-7), and is readily distinguished by its black, heavy, magnetic nature. It mostly appears to occur as rounded boudins to a few metres diameter in amphibolitic to serpentinitic rocks.

#### Hand specimen

The rock type is variable but is mostly very dark metallic grey or black, coarse-grained, disseminated to massive magnetite, with grey-green-white flecks and bands and patches of unfoliated silicates and disseminated coarse-grained pyrite.

#### Petrography

The polished thin sections indicate that this rock type, representing the main ore bodies, is highly variable in constitution but is typically composed mostly of coarse grained brecciated subhedral grains (up to 6 mm diameter) and clasts of magnetite aggregates with subordinate to minor anhedral pyrite and brecciated apatite (both to a few millimetres) in a variable, unfoliated, medium to fine-grained silicate carbonate matrix. The matrix usually includes serpentine colourless chlorite (clinocllore) talc colourless, tremolitic to actinolitic amphibole dolomite calcite. Chlorite commonly appears to have replaced biotite, from the presence of very fine rutile and/or ilmenite-rich patches (C108906), and locally appears partly altered to serpentine (C108906, C108911) and/or talc (C109073) and/or amphiboles (C109073). Some chlorite, in contrast, appears to replace serpentine (C108841) or talc (C108906, C108843). Albite is rarely moderately abundant and there is also sporadic trace quartz, brucite(?), sphene, rutile, chalcopryrite and late hematite.

The matrix in the amphibolitic rocks is locally well-foliated to mylonitised (C108971, C108965), but much is relatively unfoliated, especially in the pyroxenites (e.g. C108906, C109077, C109073, C109076). There is common evidence for an early, coarse-grained granoblastic texture (e.g. C108906,

C108907, C108841), mostly altered and retrogressed to serpentine, talc, carbonate, etc. There are usually minor, irregular serpentine carbonate veinlets.

The ore minerals observed are magnetite (up to 90%), pyrite (up to 35%), minor ilmenite (up to 2%), hematite (up to 5%, usually replacing magnetite) and trace rutile and chalcopryrite (up to 1%), all mostly medium to coarse grained and massive to disseminated. Pyrite grains commonly have inclusions of magnetite, but some magnetite grains may also have pyrite inclusions. Pyrite may also have fine poikiloblastic core zones with unidentified silicate inclusions.

The hematite is probably all mostly a late (post-tectonic) replacement phase, while apatite, magnetite and pyrite all appear paragenetically early, being mostly highly brecciated and deformed.

**Table 11**

*Mineralogy summary; H2*

Wt. %	Max.	Min.
Carbonate	25	0
Dolomite	30	0
Calcite	30	0
Quartz	5	0
Albite	15	0
Amphibole	55	0
Chlorite	20	0
Serpentine	50	0
Talc	40	0
Biotite	1	0
Apatite	10	0
Leucoxene	2	0
Magnetite	90	10
Hematite	5	0
Pyrite	35	0

(24 samples examined)

#### Rock type and genesis

This is a semi-massive magnetite, perhaps an Fe-metasomatised skarn or serpentinite, probably derived from an impure magnesian skarn or ultimately an altered sedimentary carbonate. There is no mineralogical or textural indication of an igneous origin (as an Fe-rich magma), and the similarity to associated carbonate rocks and skarns in Al, Ti and Cr in preliminary geochemistry supports a sedimentary origin. Field relationships also indicate a spatial relationship to carbonate rocks and serpentinite, rather than being intrusive.

#### Pyrite rich-rocks (H2p)

##### Definition

This rock type was defined here for some pyrite-rich mineralised rocks (i.e. greater than 15% ore minerals), with pyrite greater than magnetite but of highly variable mineralogy, forming a relatively minor part of the Host Sequence.

**Main ABM Code:** ZMP

**Typical samples:** C109118b, C108872a

**Photographs:** C108934, C108897, C108897,  
C108869

#### Distribution and field relationships

This rock type is relatively abundant in the Host Sequence in all the visited pits in the Savage River mine (fig. 2-7), commonly in close association with the magnetite ores, and readily identified by its high pyrite content or rapid ferruginous weathering. It mostly occurs in small, discontinuous bodies in structurally complex zones, but some may be in dismembered bands and clasts.

#### Hand specimen

The samples are mostly dominated by coarse-grained, richly disseminated to massive pyrite, usually also containing lesser magnetite and grey-green-white flecks and mottles of unfoliated silicate and carbonate minerals, and little well defined banding or other structure.

#### Petrography

The polished thin sections indicate that this rock type is highly variable in constitution but the samples are typically composed largely of coarse-grained anhedral crystals and clasts of pyrite (up to 6 mm) commonly, but not always, with subordinate to minor anhedral apatite and magnetite (both to a few millimetres) in a highly variable, medium to fine-grained silicate carbonate matrix. The matrix usually includes serpentine talc colourless tremolitic to actinolitic amphibole pale green chlorite albite quartz calcite dolomite. There is also sporadic minor to trace tourmaline, chalcopyrite and hematite.

The matrix is commonly highly foliated and mylonitised (C108934, C109152b), in contrast to most magnetite-rich rocks. Pyrite may be drawn out into the foliation, showing it is locally pre- or

syn-deformational (C109118a), but in other rocks it overprints the foliation (C109152b).

The ore minerals observed are major pyrite (up to 80%), magnetite (up to 20%), and trace hematite (up to 1%) and chalcopyrite (up to 5%), all mostly coarse grained and disseminated to semi-massive.

The hematite is probably mostly a late (post-tectonic) replacement phase; apatite, magnetite, chalcopyrite and pyrite appear paragenetically early, being highly deformed.

**Table 13**

*Mineralogy summary: H2p*

Wt. %	Max.	Min.
Dolomite	65	0
Calcite	30	0
Quartz	15	0
Albite	60	0
Epidote	5	0
Amphibole	30	0
Chlorite	20	0
Serpentine	10	0
Talc	45	0
Tourmaline	10	0
Apatite	10	0
Leucosene	5	0
Magnetite	20	0
Hematite	1	0
Pyrite	80	10
Chalcopyrite	5	0

(15 samples examined)

#### Rock type and genesis

The rock type is a semi-massive pyritite, probably derived from local hydrothermal replacement of reactive rocks, perhaps including impure magnesian skarn or altered carbonate. Alternatively some may be of exhalative or sedimentary origin, but there is no indication of any definitive sedimentary banding or continuity of any pyrite-rich layers.

## Apatite rich-rocks (H2ap)

### Definition

This rock type was defined here for some unusual apatite-rich rocks, forming a very minor part of the Host Sequence, containing greater than 15% of ore and/or probable hydrothermal minerals (magnetite, pyrite and apatite), and having apatite greater than magnetite and apatite greater than pyrite.

**Main ABM code:** ?

**Typical samples:** C108944c

**Photograph:** C109157, C108944

### Distribution and field relationships

This rock type is probably a very minor component in the Host Sequence in the North and Central pits in the Savage River mine (fig. 2-7). It is usually found in or close to the magnetite ore and is not always readily identified in the field. It may only occur as small, disrupted layers or nodules, but this is uncertain.

### Hand specimen

This rock type is variable in appearance but is mostly white to grey or pink and granular, with coarse-grained, disseminated to massive magnetite and/or pyrite, with grey-green-white flecks and mottles of unfoliated silicates, usually associated with the main ore bodies.

### Petrography

The polished thin sections indicate that this rock type is highly variable in composition. This type is typically composed largely of coarse-grained brecciated blocky crystals and irregular clasts of apatite (up to 6 mm) with subordinate anhedral pyrite and magnetite (both to a few millimetres) in a highly variable, unfoliated, medium to fine-grained silicate carbonate matrix. This matrix usually includes serpentine talc pale green to colourless tremolitic to actinolitic amphibole dolomite. There are also sporadic traces of green-brown biotite (C108944), pale green chlorite, quartz, chalcopyrite and albite.

The matrix is partly foliated and mylonitised, with a suggestion of an original granoblastic texture prior to retrogression.

The opaque minerals observed are major magnetite (up to 90%), minor pyrite (up to 35%) and trace

chalcopyrite (up to 1%), all medium to coarse grained and are disseminated to massive.

The apatite, magnetite and pyrite appear paragenetically early, all being highly deformed. Fine to coarse apatite grains are commonly included in poikiloblastic magnetite and pyrite grains, but not the opposite, suggesting that apatite may pre-date the magnetite and pyrite.

**Table 12**

*Mineralogy summary: H2ap*

Wt. %	Max.	Min.
Dolomite	20	5
Quartz	2	0
Albite	5	0
Amphibole	10	0
Chlorite	2	0
Serpentine	45	0
Talc	30	0
Biotite	5	0
Apatite	40	20
Magnetite	18	5
Pyrite	35	1

(3 samples examined)

### Rock type and genesis

Apatite appears to be quite early in these rocks and is not vein related; it probably represents altered sedimentary phosphate nodules or layers. The rock is unlikely to be a phosphate- and Fe-metasomatised carbonate or serpentinite, as apatite appears to pre-date magnetite and serpentine. The apatite seems unlikely to be remobilised from the surrounding phosphate-bearing mafic rocks into the carbonate rocks or ores during metasomatic alteration as no evidence or mechanism is known for this (no apatite was observed in any veins). Its carbonate association and lack of igneous textures indicates that the rock is unlikely to be of an igneous origin.

The preliminary geochemistry of the host rocks indicates that they are REE-poor; postulated magnetite-apatite rich igneous rocks of Kiruna-style are generally REE-rich (Smith *et al.*, 2007). There is still considerable debate as to the actual existence of Si and Ti-poor, Fe-P rich magmas as postulated for precursors to the Kiruna and other magnetite deposits (Bookstrom, 1995; Corriveau, 2006).

## ■ Serpentinite (H3)

### Definition

This rock type was defined here for weakly mineralised serpentine-rich rocks, forming a major part of the Host Sequence, defined here as having serpentine greater than 25% and combined magnetite + pyrite up to 15%.

**Main ABM codes:** SLO, UOS?

**Typical samples:** C108882, C108949

**Photographs:** C108882, C108954, C108949

### Distribution and field relationships

This rock type is a common part of the Host Sequence in the North Pit, and was also found in the South Pit and along the Savage River in the Savage River mine area (fig. 2-7). It is usually found in irregular bodies close to magnetite ore zones, and grades into these. It is usually distinguishable in the field by its relatively bright green colour and typical slickensided nature.

### Hand specimen

These rocks are a pale to bright green to grey, massive, fine grained with weak foliation, and usually show some disseminated mineralisation (magnetite and pyrite) and carbonate spotting and veining.

### Petrography

The polished thin sections indicate that the rock type is composed mostly of fine-grained, pale green serpentine and/or dolomite, usually with only minor talc pale green chlorite (clinochlore). There are also traces of opaque minerals and sporadic coarse apatite. The serpentine occurs mostly as coarse-grained, foliated to decussate or radiating aggregates of platy to micaceous antigorite, probably of retrograde metamorphic origin, and locally retrogressively totally replacing another granular phase (forsterite or periclase? e.g. C108882). There is usually abundant, mostly very finely disseminated, carbonate (principally dolomite) and usually some coarse ovoid carbonate porphyroblasts to 2 mm (C108949, C108950). The chlorite is mostly disseminated in small patches (pseudomorphing biotite?), which appear to be altering to serpentine (C108969). The matrix may contain abundant clasts and/or unidentified rounded

porphyroblasts (brucite, periclase or forsterite?), pseudomorphed to serpentine or talc magnetite (C109158).

There are minor serpentine-carbonate, chlorite and quartz-carbonate veinlets. The matrix varies from highly foliated to essentially unfoliated.

The opaque minerals observed are minor disseminated pyrite (up to 10%, fine to coarse grained) and magnetite (up to 10%, coarse grained, some with fine, equant serpentine inclusions; C108954).

The highly poikiloblastic magnetite appears to be post-dating an early fine-grained hornfelsic fabric, pre-dating the major deformation (and probably the serpentinisation). The serpentinite matrix coarsened during later metamorphism, showing that the magnetite is pre or syn this late metamorphic fabric. The pyrite is non-poikiloblastic and appears paragenetically later, overprinting the serpentinite.

**Table 14**

*Mineralogy summary*

Wt.%	Max.	Min.
Carbonate	5	0
Dolomite	70	0
Calcite	5	0
Quartz	2	0
Chlorite	10	0
Serpentine	85	30
Talc	10	0
Apatite	1	0
Magnetite	10	0
Pyrite	10	0

(7 samples studied)

### Rock type and genesis

This is a serpentinite or serpentine-dolomite rock, perhaps a retrogressed magnesian (forsterite or brucite?) skarn; the mineralogy does not fit an ultramafic igneous rock (particularly lacking chromite). This interpretation is supported by preliminary, unpublished, geochemistry, showing low Ni and Cr, and will be further examined in our next report. The field relationships also indicate a relationship to carbonate rocks.

## ■ Silicate-dolomite rocks (H4)

### Definition

This rock type was defined here for weakly mineralised, non-feldspathic, talc-chlorite-carbonate-quartz rich rocks, forming a major part of the Host Sequence. This type is largely equivalent to the 'Talc schist' mapped in the mine by ABM, and is perhaps also related to the chlorite-dolomite-muscovite unit mapped by ABM (fig. 2-7). By our definition this unit has total silicates greater than carbonates, contains 20-50% carbonate minerals (mostly dolomite), greater than 30% silicate minerals (mostly chlorite, talc, quartz and serpentine) and up to 20% combined magnetite-pyrite- chalcopyrite.

**Main ABM code:** SLC, UXT, etc.

**Typical samples:** C108821a, C108978a, C109140a

**Photographs:** C108976, C108821

### Distribution and field relationships

This rock type is abundant in the Host Sequence in the North Pit, and less commonly in the South Pit in the Savage River mine (fig. 2-7). It is usually found close to the ore and is usually identified in the field by its subordinate dolomite content and usually its chloritic or talcose nature.

### Hand specimen

These rocks are pale green-grey to bluish grey, massive, fine to medium grained, with weak to moderate foliation. There is commonly minor disseminated, coarse-grained and rounded pyrite (a few millimetres in diameter) and carbonate veining. The rock may feel quite talcose along cleaved surfaces, although the talc component is usually minor to subordinate.

### Petrography

The polished thin sections indicate that the rock type is highly variable but is typically composed mostly of sub-equal amounts of carbonates (dolomite calcite),

colourless to green chlorite (clinochlore) and talc. Minor to trace phases include magnesite, quartz, colourless (tremolitic) amphibole, ore minerals and sphene.

The rock is commonly inhomogeneous, highly foliated, banded and with a contorted foliation.

The ore minerals observed are coarse-grained, disseminated magnetite (up to 5%, highly brecciated) and pyrite (up to 5%).

**Table 15**

*Mineralogy summary*

Wt. %	Max.	Min.
Dolomite	50	0
Calcite	20	0
Magnesite	10	0
Quartz	40	0
Epidote	10	0
Amphibole	5	0
Chlorite	35	0
Talc	70	0
Muscovite	10	0
Tourmaline	10	0
Apatite	1	0
Leucoxene	5	0
Magnetite	8	0
Pyrite	8	0
Chalcopyrite	1	0

(11 samples studied)

### Rock type and genesis

The rock type is a chlorite talc dolomite or dolomitic talc-chlorite schist, probably originally an impure magnesian and/or dolomitic sedimentary rock with some highly variable amounts of intercalated siliceous and mafic tuffaceous sediment. It was probably metasomatised to a magnesian skarn, later retrogressed and variably affected by mylonitic deformation.

## ■ Dolostone (H5)

### Definition

This rock type was defined here for unmineralised, dolomite-dominant rocks, forming an important part of the Host Sequence, with dolomite 50–100%, total silicates (quartz, serpentine, chlorite and talc) up to 50%, and mineralisation up to 15%.

**Main ABM code:** SLO

**Typical samples:** C108825, C108821b

**Photographs:** C109159, C109140c, C108947,  
C108881, C108947, C108827,  
C108802

### Distribution and field relationships

This rock type is abundant in the Host Sequence in the North and South pits in the Savage River mine (fig. 2-7). It is usually found with magnesite bodies but is not always readily distinguished in the field.

### Hand specimen

The rock sample is a white to pale grey, massive, fine grained rock with no foliation except in some chloritic and/or talcose lamellae, and occurs as tabular bodies from a few centimetres to several metres thick. It is usually less yellow than magnesite when weathered.

### Petrography

The polished thin sections indicate that this rock type is composed mostly of dolomite with sporadic subordinate to minor magnesite, quartz and talc, and minor to trace calcite, serpentine, chlorite, sphene and ore minerals. There are locally some carbonaceous zones that contain up to 10% of poorly crystallised

organic matter (pyrobitumen to protographite), mostly in thin layers (C109140c).

It is usually only weakly foliated or banded, and may have various types of veinlets, rarely mineralised. The carbonaceous layers appear to represent late fractures rather than sedimentary horizons.

The ore minerals observed are minor disseminated, coarse-grained magnetite (up to 10%) and pyrite (up to 10%), and trace hematite and chalcocopyrite (up to 1%).

**Table 16**

*Mineralogy summary*

Wt. %	Max.	Min.
Dolomite	92	50
Calcite	10	0
Magnesite	45	0
Quartz	25	0
Chlorite	20	0
Serpentine	10	0
Talc	25	0
Muscovite	5	0
Leucosene	2	0
Magnetite	10	0
Hematite	2	0
Pyrite	8	0
Chalcocopyrite	2	0

(16 samples studied)

### Rock type and genesis

This is a metamorphosed and altered sedimentary dolostone, mostly with some minor intermixed (probably mostly sedimentary but possibly also tectonically?) siliceous and mafic-derived sedimentary material.

## ■ Magnesite-stone (H6)

### Definition

This classification was defined here for all magnesite-dominated rock types, comprising much of the carbonate-rich rocks in the Host Sequence, with magnesite 50–100%, total silicates (quartz, serpentine, chlorite and talc) up to 50% and mineralisation up to 15%.

**Main ABM code:** SMO

**Typical samples:** C109069, C109167

**Photographs:** C109168, C108881

### Distribution and field relationships

These rock types occur in the Host Sequence in the North and South pits and South Lens in the Savage River mine, as well at Long Plains (fig. 2-7) and a number of other sites in the Bowry Formation to the north and south.

### Hand specimen

This is a fine-grained, white (yellow-weathering), massive rock with no obvious inhomogeneity or foliation, and is usually found in tabular bodies a few metres thick. It is commonly nodular, probably representing a clast-supported sedimentary breccia with white intra-clastic dolomite.

### Petrography

The polished thin section indicates that the rock is composed mostly of fine-grained (up to 0.5 mm)

magnesite (up to 95%), usually with subordinate dolomite (coarse grained, intra-clastic or vein-style) and sporadic subordinate to trace quartz grains or crystals and talc (disseminated flakes). There are commonly traces of calcite, chlorite and ore minerals.

The rock is only very weakly foliated, but commonly has calcite and dolomite veining.

The ore minerals observed are minor to trace disseminated magnetite (up to 5%), pyrite (up to 7%) and chalcopyrite (up to 2%).

**Table 17**

*Mineralogy summary*

Wt. %	Max.	Min.
Dolomite	35	0
Calcite	5	0
Magnesite	95	40
Quartz	40	0
Chlorite	10	0
Talc	15	0
Magnetite	5	0
Pyrite	7	0
Chalcopyrite	2	0

(6 samples examined)

### Rock type and genesis

This is probably a diagenetically altered, metamorphosed, metasomatised and altered sedimentary carbonate rock.

## ■ Mafic meta-volcaniclastic rocks (H7)

### Definition

This rock type was defined here for weakly mineralised mafic-rich metamorphic rocks, forming a major part of the Host Sequence, and interpreted from mineralogy and textures as being sedimentary or volcaniclastic. By our definition they contain 25–60% mafic minerals, up to 60% albite and up to 10% carbonate minerals, and lack any field or petrographic evidence for an igneous origin.

**Main ABM code:** SXC, MXB, MXH etc.

**Typical samples:** C108833, C108961, C108839, C109165

**Photographs:** C109132, C109124b, C109107, C109100, C109090, C108942, C108839

### Distribution and field relationships

This rock type is abundant in the Host Sequence in all the pits in the Savage River mine (fig. 2–7), and is recognisable by its mafic nature, common weak banding, and moderate magnetic susceptibility.

### Hand specimen

The rock sample is typically a green-grey, fine to medium-grained rock with some diffuse banding and a moderate foliation, and usually shows some finely dispersed magnetite and pyrite.

### Petrography

The polished thin sections indicate that these rocks are highly variable in composition and texture, and could perhaps be subdivided further on the basis of their mineralogy and geochemistry (although the differences are probably not usually obvious in the field). Some are rich in feldspar (albite), some in amphibole, some in epidote and some in chlorite and/or biotite. All of these phases are minor or lacking in various other samples of the rock type. They are mostly commonly composed of sub-equal amounts of green chlorite, albite, blue-green-brown amphibole and yellow to colourless epidote, with sporadic abundant green-brown biotite and quartz, plus sporadic minor to trace muscovite, talc, K-feldspar, calcite, dark blue-green-brown tourmaline (schorl), magnetite, pyrite and leucoxene (mostly sphene). Plagioclase occurs mostly as medium-grained (up to 1.5 mm), irregular to rounded, sub-equant crystals (possibly partly detrital grains, but sometimes highly poikiloblastic and thus syngenetic or metasomatic; C109124). These albite grains are commonly concentrated in bands, or less commonly as a fine-grained groundmass phase. Epidote-clinozoisite may apparently take the place of albite in some rocks.

The amphibole occurs in a variety of colours and textures including:

(a) an early pale brown, possibly igneous hornblende (C108870);

(b) porphyroblasts of blue-mauve glaucophane-rich amphibole (C109100);

(c) very widespread, late-stage, pale to medium blue-green in colour, commonly fine grained, probably barroisite-winchite-actinolite compositions.

The significance of glaucophane indicating a high-pressure origin for the Bowry Formation was discussed by Turner and Bottrill (2001). Some very fine-grained amphibole-albite-chlorite aggregates may represent retrogressed glaucophane (C108884). The amphiboles may occur in bands (C109107) or coarse relict grains (C108108).

Chlorite (probably largely replacing biotite) and/or green-brown biotite are common, usually fine grained in the matrix and in bands. Tourmaline (schorl!) is commonly disseminated through the rocks in small amounts as coarse to fine grains, but is commonly concentrated in thin bands (late fractures?; C109107). Tourmaline sometimes appears to be overprinting other minerals (C109132), but is commonly deformed and brecciated (C109124b). Quartz is apparently restricted to boudinaged veins (C109098). Leucoxene (probably mostly fine sphene, commonly replacing rutile?) is ubiquitous in fine-grained patches in the matrix and sometimes may highlight original clast shapes (C109150).

These rocks are usually relatively weakly foliated although some show a strong foliation (C109124b) or several weak foliations at large angles (C109107). The least deformed rocks appear to be composed mostly of rounded to oblate feldspar and mafic mineral and/or lithic clasts, and appear hornfelsic (C109132). These clasts may have originally been detrital grains, from the clast size, shape and common distribution in bands, despite a local cataclastic to mylonitic overprint. Igneous textures are well preserved in some other rocks in the mine, despite the alteration and deformation (see group ID). Traces of quartz grains, muscovite and rounded tourmaline and zircon in mafic rocks support a sedimentary origin for the Eastern and Western sequences but were rare or absent in this unit, but they are otherwise similar. Carbonate minerals (dominantly calcite) are mostly disseminated but also occur in veins, usually with quartz chlorite epidote amphibole albite. Some quartz albite carbonate veins are pre-deformational and boudinaged (C108957), but others are undeformed.

The main ore minerals observed are ubiquitous anhedral pyrite (up to 15%; up to 0.2 mm) and magnetite (up to 10%; up to 0.2 mm) both disseminated and in veinlets. Traces of hematite and chalcopyrite (up to 3%) are also common. Magnetite is generally sieve-textured. Magnetite and pyrite are commonly euhedral and appear cogenetic and mostly recrystallised or undeformed in most samples, perhaps suggesting a post-deformational origin (C108839, C109070). Some samples show some weak

pressure shadows, wrapping of foliation or some minor brecciation (e.g. C109107, C109098).

**Table 18**  
*Mineralogy summary*

Wt.%	Max.	Min.
Carbonate	15	0
Dolomite	10	0
Calcite	10	0
Quartz	20	0
K-Feldspar	10	0
Albite	50	0
Epidote	30	0
Amphibole	65	0
Chlorite	40	0
Serpentine	5	0
Talc	10	0
Biotite	25	0
Muscovite	10	0
Tourmaline	10	0
Apatite	2	0
Leucoxene	5	0
Magnetite	10	0
Hematite	3	0
Pyrite	15	0
Chalcopyrite	3	0

(27 samples studied)

#### **Rock type and genesis**

This rock is probably a metamafic tuff and/or sandstone sequence, and is similar to the Eastern Wall and Western Wall lithologies. It differs from these in mostly containing less quartz and chlorite and more amphibole, albite and biotite, perhaps due to higher metamorphic grade and/or less retrogression, or perhaps different alteration styles. It also has more mineralisation (albeit mostly still minor). Some of the more feldspathic units may grade into andesitic compositions, but most appear basaltic; this awaits geochemistry. The high mineralogical variation suggests variable degrees of sodic, potassic and calcic alteration within different zones. The biotite probably indicates some early potassic alteration, and the albite-rich rocks some sodic alteration. Other factors, including variably penetrative metamorphic events, could also play important roles in having highly variable mineralogy in these rocks.

## **Eastern Wall Mafic Sequence (EW)**

### **Definition**

This stratigraphic unit is essentially identical to the Eastern Wall Carbonate-Mafic Sequence used informally by ABM geologists for relatively unmineralised mafic schist and amphibolite along the eastern side of the Main Host assemblage in the Bowry Formation (unpublished ABM mapping). It contains greater than 30% mafic minerals, 10–60% albite, and up to 15% carbonate.

**Main ABM code:** MXR, MXB, OXC

**Typical samples:** C108815, C108879

**Photographs:** C108879, C108815

### **Distribution and field relationships**

This unit dominates the eastern walls in all the pits in the Savage River mine, and is usually well exposed in these areas (fig. 2–7).

### **Hand specimen**

These are fine-grained, green-grey massive to finely schistose rocks with weak to moderate foliation, some lamination, and little or no obvious mineralisation and veining.

### **Petrography**

The polished thin sections indicate that these rocks are generally mafic in composition but are highly variable in mineralogy, and only albite (up to 55%) and chlorite appear to be ubiquitous throughout them. Blue-green amphibole, albite, epidote, quartz and chlorite may all be dominant or sub-dominant in various samples and very minor or absent in some others, while calcite, muscovite and biotite are also locally abundant. K-feldspar, pyrite, magnetite, leucoxene, hematite and tourmaline are usually present in very minor to trace amounts. Quartz may occur as fine-grained, rounded to angular clasts to 0.4 mm (detrital grains?). Some epidote is coarse and some extremely fine grained, the latter perhaps due to a late-stage, low temperature replacement of blue amphibole? Biotite is commonly green in colour and typically partly chloritised.

The rock is moderately foliated and banded (sedimentary?), mostly in terms of albite/amphibole ratios. There are common, discontinuous, boudinaged carbonate and quartz veinlets.

A trace of anhedral pyrite is relatively common (up to 2%, up to 0.2 mm), and occurs both as disseminated grains and in veinlets. Traces of disseminated magnetite (up to 4%) and hematite (up to 1%) are also common.

**Table 19***Mineralogy summary: EW*

Wt. %	Max.	Min.
Carbonate	5	0
Calcite	10	0
Quartz	25	0
K-Feldspar	5	0
Albite	55	10
Epidote	25	0
Amphibole	40	0
Chlorite	35	10
Biotite	20	0
Muscovite	10	0
Tourmaline	1	0
Leucoxene	5	0
Magnetite	4	0
Hematite	1	0
Pyrite	2	0

(7 samples studied)

**Rock type and genesis**

This unit is probably dominantly an altered and metamorphosed metamafic tuff and/or tuffaceous sandstone sequence with a minor component of clastic rocks of a more quartzose, micaceous and/or feldspathic composition. The rocks resemble lithic arenite of the Kanunah Subgroup. The biotite and muscovite probably indicate some early potassic alteration, and the albite-rich zones some sodic alteration.

**Eastern Wall carbonate-rich zones (EWC)****Definition**

This rock type was defined here for mafic-rich amphibolite, mylonite and schist, forming a major part of the Eastern Wall sequence, somewhat equivalent to the Banded Eastern Wall Carbonate-Mafic assemblage, which we were unable to discriminate in the field (unpublished ABM mapping). It is defined here as containing greater than 20% carbonate minerals and greater than 30% mafic minerals.

**Main ABM code:** OXR**Typical samples:** C108814**Photographs:** C108982, C108814**Distribution and field relationships**

This unit dominates the eastern walls in all the pits in the Savage River mine, and is usually well exposed in these areas (fig. 2-7).

**Hand specimen**

These are fine-grained, green-grey massive to finely schistose rocks with weak to moderate foliation, some

crude lamination or banding, and little or no obvious mineralisation or veining. They are not readily distinguished in the field from EW except by tests for carbonate.

**Petrography**

The polished thin sections indicate that the rocks are composed mostly of green chlorite, albite, quartz and carbonate, commonly with sporadic subordinate biotite, blue-green amphibole, epidote and minor muscovite, and generally traces of tourmaline, pyrite and leucoxene. The carbonates are calcite and/or dolomite. Quartz may occur as fine-grained, rounded to angular clasts to 0.4 mm. Albite mostly occurs as rounded crystals to 0.4 mm. Some epidote is coarse and some extremely fine grained, perhaps due to a late stage, low temperature, calcic alteration event. Blue amphibole is largely retrogressed to fine-grained aggregates of various minerals. Biotite is brownish green and typically partly chloritised.

The rock is highly foliated and strongly banded, usually with alternating bands, to a few millimetres thick, of carbonate albite epidote and chlorite amphibole epidote. Locally there are commonly discontinuous, boudinaged carbonate and quartz veinlets.

Anhedral pyrite is common (up to 2%; up to 0.2 mm), occurring both as disseminated grains and in veinlets.

**Table 20***Mineralogy summary: EWC*

Wt. %	Max.	Min.
Dolomite	20	0
Calcite	25	15
Quartz	20	5
Albite	20	10
Epidote	15	0
Amphibole	10	0
Chlorite	35	20
Biotite	10	0
Muscovite	5	0
Tourmaline	1	0
Leucoxene	5	0
Pyrite	2	0

(4 samples studied)

**Rock type and genesis**

This unit is probably an altered and metamorphosed metamafic tuff and/or tuffaceous sandstone sequence. It is a carbonate-rich version of the Eastern Wall sequence.

## Armstrong Creek Mafic Schist (AC)

### Definition

This stratigraphic unit is used informally by ABM geologists for relatively unmineralised chlorite schist along the eastern side of the Bowry Formation (unpublished ABM mapping). The unit appears very complex and variable; the few samples examined include talc-bearing schist with up to 90% chlorite, Oonah Formation-like chloritic quartzite (up to 85% quartz) and some amphibolitic rocks (tuffaceous beds?). Some intrusive dolerite has also been mapped as this unit (unpublished ABM mapping). Further study is required for better characterisation. This unit may equate to the Ahrberg Group Correlate, as defined by Holm and Berry (2002). The samples examined in this report suggest that the unit could perhaps be subdivided lithologically (e.g. into quartzitic, volcanoclastic, talcose and quartz-chlorite units) but there is insufficient sampling to do this at present.

**Main ABM code:** OXC

**Typical samples:** C109066a, C109066b, C109083

**Photographs:** C109141, C109066a

### Distribution and field relationships

This unit dominates the area between the Oonah Formation and the eastern walls of all the pits in the Savage River mine, and is moderately well exposed in the Savage River gorge and along the Pipeline Track (fig. 2-7).

### Hand specimen

In hand specimen this is typically a pale grey, streakily laminated fine-grained schistose or quartzitic rock with an irregular phyllitic foliation and is only moderately indurated. No veining or mineralisation was visible.

### Petrography

The samples collected indicate that these rocks are highly varied in composition, but are probably dominated by quartz-chlorite schist. One sample is an amphibole-rich meta-basaltic arenaceous or volcanoclastic rock (tuff?; C109083), one is a chloritite or chlorite schist (C109141), one is a quartzite or quartz schist (C109066a), and one is a talc-chlorite rock (C109143).

The quartz schist or chloritic quartzite (C109066a) resembles the Oonah Formation lithologies, and has a distinctly clastic texture, with thin chlorite-muscovite lamellae (replacing biotite?) wrapping about stressed and recrystallised ovoid quartz clasts to 0.3 mm diameter, indicative of a metamorphosed, impure quartz sandstone in origin, perhaps with minor tuffaceous sediment. The quartz chlorite schists are

composed of sub-equal amounts of green chlorite and quartz, with sporadic minor to trace albite, muscovite, pyrite and leucoxene. These rocks probably represent much more tuffaceous sandstone and siltstone.

One rock (C109083) contains major amphibole and chlorite, minor albite, epidote and quartz, and traces of K-feldspar, leucoxene and pyrite. There are faint relicts of irregular to ovoid, sub-equant clasts (probably tuffaceous grains, to 0.2 mm), defined by interstitial, diffuse leucoxene patches. The rock is highly foliated but weakly banded, and there are minor albite-pyrite micro-veinlets. It is interpreted as a metamorphosed basaltic sandstone or volcanoclastic rock, with less alteration and penetrative deformation than the above rock types.

The chloritite and talc-chlorite rock are composed dominantly of green chlorite with subordinate to trace talc, and only trace quartz, leucoxene and micas, plus sporadic trace tourmaline. These quartz-poor, talc-bearing rocks may represent a very altered dolomite-bearing basaltic (volcanoclastic?) rock. They are highly deformed, and may possibly represent mylonitised carbonate and mafic-rich zones, suggesting they may actually be a part of the Host Sequence?

The only ore minerals observed in this unit are traces of anhedral pyrite (up to 3%; up to 0.2 mm), occurring as disseminated grains and in micro-veinlets.

**Table 21**

*Mineralogy summary: AC*

Wt. %	Max.	Min.
Quartz	85	2
K-Feldspar	5	0
Albite	10	0
Epidote	10	0
Amphibole	30	0
Chlorite	90	10
Talc	20	0
Muscovite	10	0
Tourmaline	2	0
Leucoxene	5	0
Pyrite	3	0

(7 samples studied)

### Rock type and genesis

This unit is probably an altered and metamorphosed metamafic to quartz sandstone sequence with some minor mafic tuff beds and a possible altered carbonate-rich mafic mylonitic zone.

There is some doubt as to the attribution of some of the rocks mapped as this unit north of the main pit. The presence of talc-chlorite rocks is strongly suggestive of mylonitised, mixed mafic and carbonate-bearing rocks in the Host Sequence

## Oonah Formation (OO)

### Definition

This is a long-standing stratigraphic name for Neoproterozoic micaceous quartzite, quartz phyllite and quartz-muscovite schist, widespread in northwest Tasmania, with stratigraphic correlates identified from Hibbs Bay in the southwest, north to Burnie (Turner *et al.*, 1991). It may be a time equivalent of the Rocky Cape Group (Holm *et al.*, 2003).

**Main ABM code:** SQO, SXQ

**Typical Sample:** C109169

**Photograph:** C109169

### Distribution and field relationships

This unit dominates the area east of Savage River, west to the Meredith Granite, and south to Granville Harbour and beyond, but its extent is poorly defined to the north. It is well exposed in cuttings along the roads from Savage River township to the mine and to Corinna (fig. 2-7).

### Hand specimen

In hand specimen this is a pale grey, streakily laminated fine-grained schistose quartzitic rock with an irregular phyllitic foliation and is only moderately indurated. No veining or mineralisation was visible.

### Petrography

The polished thin section indicates that the one rock sampled is composed mostly (~85%) of fine-grained

(up to 0.5 mm) quartz with flecks and laminae of fine-grained green chlorite and white mica (probably muscovite). There is a trace of fine-grained leucoxene and tourmaline (probably detrital?). Weathered, leached spots are of uncertain origin (feldspars?). The layering is probably mostly a strong tectonic foliation, with elongated quartz grains, and is strongly crenulated, with no discernable primary textures.

**Table 22**

*Mineralogy summary: OO*

Wt%	
Quartz	85
Chlorite	5
Muscovite	10
Tourmaline	1
Leucoxene	2

(1 sample studied)

### Rock type and genesis

The rock is a chloritic and micaceous quartz phyllite, probably of greenschist metamorphic grade. It was probably a quartz-rich siltstone or fine sandstone, but definitive primary textures were not observed as the rock is totally recrystallised.

## Intrusive rocks (metadolerite) (ID)

### Definition

These mafic rocks occur sporadically. They are variable in grain size from fine to coarse grained and can be vesicular or porphyritic. Although some could be termed basalt or gabbro, the restricted size of most known bodies is supportive of them being dyke or sill-like bodies, largely boudinaged.

**Main ABM code:** MDO

**Typical samples:** C109068, C108946

**Photographs:** C109103, C109089, C109089,  
C109086, C109085, C109085,  
C109074, C109068, C108943

### Distribution and field relationships

This rock type has been seen in small bodies in the South and Centre pits, as well as the Savage River gorge cutting through the Host Sequence, and in drill core from the North Pit (fig. 2-7). One fine-grained dyke (up to 0.3 m wide; sample C109085) can be seen to cut another, more massive coarser-grained metadolerite (C109084) in outcrop in the Savage River gorge.

### Hand specimen

The rock samples are dark green-grey, fine-grained rocks with some spotting but no prominent mineralisation or foliation.

### Petrography

The polished thin sections indicate that the rocks are mineralogically highly variable and may be variously composed of blue-green amphibole albite green chlorite epidote biotite quartz calcite. The main three assemblages are:

- (a) albite-amphibole;
- (b) epidote-amphibole; and
- (c) albite-amphibole-biotite/chlorite.

There is sporadic minor to trace tourmaline (coarse spherulitic aggregates to 2 mm, possibly altered

amygdules?), and skeletal leucoxene (probably microcrystalline sphene?) aggregates to 0.5 mm represent altered but undeformed titanomagnetite grains.

The grain size of these rocks varies from about 0.5-8 mm, and the rocks are relatively homogeneous and unfoliated. Some original ophitic textures are present, and there are minor veinlets of quartz, albite and carbonate. Altered amygdules are probably represented by rounded to ovoid aggregates of albite chlorite epidote pyrite, from about 0.5-10 mm in diameter, in some rocks (e.g. C109085). Calcite occurs mostly as veins and clots (perhaps boudinaged veins or altered feldspars?).

The opaque minerals observed are sporadic magnetite (up to 8%), ubiquitous pyrite (up to 8%) and trace chalcopyrite.

**Table 23**

*Mineralogy summary: ID*

Wt. %	Max.	Min.
Calcite	25	0
Quartz	20	0
Albite	55	0
Epidote	50	0
Amphibole	60	0
Chlorite	40	0
Biotite	35	0
Tourmaline	2	0
Leucoxene	5	0
Magnetite	8	0
Pyrite	8	0

(12 samples)

### Rock type and genesis

These rocks are probably metamorphosed and metasomatised dolerite; some may have been basalt or gabbro, although field relationships suggest little size or continuity, and dolerite better fits most samples in terms of textures and original grain size. The biotite probably indicates some early potassic alteration.

## Mylonite (Y)

### Definition

This category was used for rocks where the nature of the original rock type is almost totally obscured by mylonitic or cataclastic deformation. The main mineralised rocks are also partly mylonitic but are omitted here by definition.

**Main ABM code:** OFO

**Typical samples:** C109160, C109139, C108874

**Photographs:** C109138, C108971, C108971,  
C108826

### Distribution and field relationships

This rock type is sporadically present in many areas, but is particularly common throughout much of the Bowry Formation, mostly in relatively narrow, steeply dipping zones (fig. 2-7).

### Hand specimen

These rock types are highly variable but are commonly laminated black-white-grey-green rocks with phyllitic to mylonitic or cataclastic textures, and with usually minor to traces of disseminated pyrite and/or magnetite grains. Some of the more micaceous rocks may have highly contorted foliation.

### Petrography

The polished thin sections indicate that this rock type is most commonly composed of fine to coarse-grained, blue-green and brown amphibole chlorite talc carbonates (calcite dolomite). There is also sporadic dominant to subdominant quartz, albite and biotite, plus minor amounts of tourmaline, magnesite, leucoxene, carbonaceous matter (pyrobitumen?, e.g. C108822, up to 10%) and opaque minerals. Porphyroclasts include albite, quartz, epidote, tourmaline, pyrite, magnetite and amphiboles. Albite porphyroblasts may contain fine amphibole inclusions indicating an earlier, now randomly rotated foliation in an amphibole-poor, chloritic matrix (e.g. C109160). The amphiboles may show complex zoning, some with brown cores, blue overgrowths and late pale green to colourless overgrowths (e.g. C108971); this may relate to sodic alteration as much as metamorphism, and needs further study.

The matrix is variable from cataclastic to mylonitic, but is mostly recrystallised and is usually weakly to moderately foliated. In the more schistose rocks the layering may be locally strongly crenulated, which suggests that the mylonitisation event is relatively early and is overprinted by metamorphic annealing and later deformation events. However the textures of some porphyroclasts (e.g. coarse albite and early blue and brown amphiboles) indicate that they post-date at least one high-grade deformational event.

The opaque minerals observed include minor magnetite (up to 5%), hematite (up to 12%) and pyrite (up to 10%), and trace chalcopyrite (up to 1%); the more mineralised mylonites grade into ore, and are described there.

**Table 24**

*Mineralogy summary: Y*

Wt.%	Max.	Min.
Carbonate	50	0
Dolomite	40	0
Calcite	40	0
Quartz	40	0
K-Feldspar	5	0
Albite	30	0
Epidote	35	0
Amphibole	70	0
Chlorite	40	0
Talc	70	0
Biotite	25	0
Tourmaline	10	0
Apatite	1	0
Leucoxene	5	0
Magnetite	5	0
Hematite	12	0
Pyrite	10	0

(18 samples studied)

### Rock type and genesis.

These rocks are relatively late stage, fault zone-related mylonites, formed by shearing in many rock types, but mostly the mafic and mineralised lithologies. They show some relatively late-stage sodic alteration.

## Brecciated Fault Material (Yb)

### Definition

This rock type was used for rocks where the origin is largely obscured by veining and/or late-stage cataclastic deformation. The main mineralised rocks are also mostly breccias but are omitted here by definition. The breccias are mineralogically complex. One important sub-type is quartz-rich breccia (Ybq), described below.

**Main ABM code:** OFO

**Typical samples:** C109104, C109094

**Photographs:** C108874

### Distribution and field relationships

This rock type is relatively abundant but sporadic within much of the Bowry Formation (fig. 2–7).

### Hand specimen

These rock types are highly variable but may be black, white, grey or green with breccia textures, commonly with multiple veins of variable mineralogy and usually contain minor vein-style pyrite.

### Petrography

The polished thin sections indicate that this rock type is variously composed of mostly angular clasts of various lithologies in a matrix variously dominated by coarse-grained dolomite, albite, chlorite, amphiboles or epidote. Many veins are poly-mineralic and there is also sporadic minor to trace calcite, talc, tourmaline, muscovite and ore minerals.

The texture is variable from clast and matrix-supported breccia to cataclasite and into mylonite.

The ore minerals observed include magnetite (up to 8%), pyrite (up to 12%) and minor chalcopryrite; the more mineralised rocks grade into ore zones.

### Rock type and genesis

These rocks are late stage poly-mineralic fault-zone breccias, with mostly only local remobilisation of rock-forming minerals and ore minerals. They are possibly of Devonian age as they show little post-breccia recrystallisation.

## Quartz-rich breccia (Ybq)

### Definition

This rock type was used for brecciated rocks (Yb) where the origin of the original rock is largely obscured by veining and/or late-stage cataclastic deformation and the rocks have a quartz-rich matrix (greater than 25%).

**Main ABM code:** OFO

**Typical samples:** C109115, C108924

**Photographs:** C108812a

### Distribution and field relationships

This rock type is common within much of the Bowry Formation (fig. 2–7).

### Hand specimen

These rock types are highly variable but may be black, grey or green with paler veins and breccia textures. They commonly contain multiple veins, are typically boudinaged and are generally unmineralised.

### Petrography

These samples are highly variable mineralogically and few very meaningful statistics could be determined. The rock type is variously composed of mostly fine to coarse-grained quartz albite chlorite carbonate minerals (dolomite and calcite). There is also sporadic trace to minor to subordinate hematite, epidote, amphiboles, talc, tourmaline, muscovite and ore minerals. Late-stage carbonates may replace albite and quartz in clasts (C108975). Quartz is relatively unstressed and relatively coarse grained.

The texture is variable from clast and matrix-supported breccia to cataclasite and mylonite.

The ore minerals observed include magnetite (up to 12%), pyrite (up to 12%), hematite (up to 25%) and minor to trace chalcopryrite; the more mineralised rocks grade into magnetite ore.

### Rock type and genesis

These rocks are late-stage, silicified fault-zone breccias, possibly of Devonian age as they show little post-breccia recrystallisation.

## Veins (V)

### Definition

This classification was used for those samples dominated by simple, non-breccia style, mostly late-stage veins. Several sub-types were defined here depending on the major mineralogy, mostly to aid interpretation of the geochemistry (in prep.): Vq (quartz rich), Vz (mineralised), Vn (carbonate-rich), Va (amphibole rich).

**Main ABM code:** VOO

**Typical Samples:** C108914, G403205, G403205,  
C108852

**Photographs:** C108938, C108863

### Distribution and field relationships

These rock types are very common throughout the Bowry Formation and surrounding units but the veins themselves are usually quite small (up to 20 mm wide in most cases). Good examples occur within the Oonah Formation in the gold deposits worked on Golden Ridge and Specimen Reef (Bottrill and Taheri, 2006; fig. 2).

### Hand specimen

The rock type comprise veins mostly only from a few millimetres to several centimetres thick, and locally up to a few metres long, with highly variable amounts of carbonate minerals, quartz, albite, amphiboles and other minerals, and may grade into breccia and boudinaged lenses and pods. The mineralogy commonly, but not invariably, reflects the surrounding rock type, suggesting that the veins are of metamorphic, non-hydrothermal origin. Quartz and tourmaline may be exceptions, mostly occurring in rocks where the components must have migrated some distance from likely source rocks.

### Petrography

These samples are highly variable mineralogically and few very meaningful statistics or summary

descriptions could be determined. They are most commonly dominated by coarse to fine-grained quartz, albite, chlorite and carbonate minerals (calcite and dolomite), with sporadic small veins variably rich in amphiboles, talc, serpentine, tourmaline, apatite and epidote. Some quartz contains fine inclusions of chlorite, amphiboles or tourmaline, suggesting it formed with them. Vein quartz is commonly boudinaged parallel to the main foliation, and this quartz is mostly highly stressed or polygonally recrystallised (C108824), indicating it was formed early in the tectonic history. Some quartz and most other vein minerals cross-cut foliations at random orientations, and appear unstressed or totally recrystallised (C108914), suggesting they were formed late in the tectonic history. Some veins are composed solely of asbestiform amphibole, formed by local minor shearing.

The ore minerals observed are locally major to minor amounts of pyrite (up to 50%), hematite (up to 20%) and chalcopyrite (up to 10%), and minor magnetite (up to 10%) in some veins, but many are unmineralised.

### Interpretation

These veins are the result of brittle deformation and locally some minor hydrothermal alteration. Some undeformed veins are probably of Devonian age, but boudinaging and recrystallisation of some other veins indicates they are earlier, possibly of Cambrian or Neoproterozoic age. Asbestiform amphibole veins are small and formed by minor local shearing. The mineralogy commonly, but not invariably, reflects the surrounding rock type, suggesting the veins are of metamorphic, non-hydrothermal origin. Quartz and tourmaline may be exceptions, commonly occurring in rocks where the components may have migrated some distance, suggesting these may be exotic and related to hydrothermal activity.

## Comparison of ABM and MRT rock types

The stratigraphic units and rock types shown on the ABM maps (Turner, 2006 and Figures 2–10) are mostly closely related to, but in part different from, the rock units described in this report. The main correlations and differences are summarised below.

<i>Code</i>	<i>ABM Rock Classification</i>	<i>MRT Rock Classification</i>	<i>Comment</i>
TG	Timbs Group	Western Ahrberg Group	Revised from Holm & Berry, 2002
AG	Ahrberg Group	Eastern Ahrberg Group	Revised from Holm & Berry, 2002
FC	Fulford Creek Schist	<i>Fulford Creek Schist</i>	No change
BF	Bowry Creek Formation	Bowry Formation	Revised from Holm & Berry, 2002
MR	Mega Ramp schist	<i>Mega Ramp schist</i>	No change
-	Box Cut carbonate sequence		Moved to H6
MRU	Dolomite-chlorite-muscovite schist	<i>Mega Ramp muscovite schist</i>	Mostly carbonate-poor, more like the Mega Ramp schist sequence
W	Western Wall 'banded schist'	Western Wall 'banded schist'	No change, but subdivided as below
W1		<i>Albitite (fine grained)</i>	New subdivision
W2	<i>Granite; tonalite</i>	<i>Coarse grained albitite</i>	Not a granite and probably not an igneous rock
W3		<i>Western Wall Mafic rocks</i>	New subdivision (metasediment?)
W4	<i>Quartz schist</i>	<i>Quartzite</i>	Relatively unfoliated
W5		<i>Quartz-amphibole rock</i>	New subdivision (metasediment?)
H	Main Host assemblage	Main Host assemblage	No change
H1		<i>Amphibolite/pyroxenite</i>	New subdivision (metasediment?)
H2	<i>Ore (undifferentiated)</i>	<i>Ore (undifferentiated)</i>	No change
H3	<i>Serpentinite</i>	<i>Serpentinite/serpentine-dolomite</i>	Metasediment
H4	<i>Talc schist</i>	<i>Silicate-dolomite rocks</i>	Commonly talc-poor
H5		<i>Dolostone</i>	New subdivision
H6		<i>Magnesite-stone</i>	New subdivision
H7		<i>Mafic metasediments</i>	New subdivision
EW	Eastern Wall mafic-carbonate Sequence	Eastern Wall Mafic Sequence	Mostly carbonate poor except near western contact
EWC	<i>Thin intervals of banded carbonate</i>	<i>Eastern Wall carbonate-rich zones</i>	Mostly disseminated carbonate in mafic rocks
-	<i>Magnesite</i>		Moved to H6
AC	Armstrong Creek mafic schist	Armstrong Creek mafic schist	No change
ID	Dolerite; mafic dykes	Intrusive rocks (dolerite)	No change

### Rock types

The suite of rocks around the Savage River mine, especially in the Bowry Formation, shows very high variability, and includes high-magnesian rocks (pyroxenite, magnesian skarn, amphibolite, and serpentinite), magnetite ores, magnesite and dolomite-rich carbonate rocks, meta-volcaniclastic rocks, meta-dolerite, meta-basaltic sandstone, albitite, mica schist and quartzite. Despite high metamorphic grades and some locally highly deformed shear zones, remnant original sedimentary and igneous textures can still be clearly observed in some rocks. Tectonically, the Bowry Formation rocks have probably all undergone several periods of deformation, some at a very high angle to others, although the intrusive and carbonate rocks usually have little foliation, and some other rock types (e.g. mineralisation) have been totally brecciated and/or recrystallised.

The Eastern Ahrberg Group is mostly a chloritic phyllite, possibly originally a mafic-derived mudstone, and one sample is a fine-grained lithic (mafic) sandstone or volcanoclastic rock.

The Oonah Formation is represented by a quartz-chlorite-muscovite schist, and is probably a metamorphosed quartzwacke or sub-litharenite. The small chlorite and leucoxene content may reflect a minor mafic tuffaceous component to the original sandy sediment.

The Mega Ramp Schist largely comprises quartz-albite chlorite dolomite schist, probably representing a sequence of highly altered, brecciated and mylonitised, mafic-rich, siliceous metasedimentary rocks. These are generally intermediate in constitution to the albitite, quartzite, carbonate rocks and mafic rocks. One important variant is a muscovite-albite quartz biotite chlorite schist, probably representing the unaltered precursor rock types to the albitite, or possibly local intercalation of more pelitic metasediments. The carbonate-rich zones may have been partly original carbonate-rich sedimentary rocks. The unit is generally weakly to moderately pyritic; some parts are highly carbonate-altered and tourmalinised.

The Western Wall Banded Schist contains interbedded albitite, metamafite (possibly metamafic sandstone tuff?), quartzite, rare pyroxenite and some quartz-amphibolite. The mafic zones (W3) are very similar to the Eastern Wall and H7 mafic lithologies, probably all mostly comprising metamorphosed mafic sandstone volcanoclastic rocks (tuff?). The quartzite (W4) is probably altered quartz-rich arenite (probably quartz arenite or sub-litharenite) or possibly chert, and is locally rich in tourmaline and pyrite. The quartz-amphibole and quartz-pyroxene bearing rocks (W5) appear relatively Ti and Al-poor (from

preliminary geochemistry) and are probably best considered calc-silicate or skarn derived from impure, siliceous carbonate rocks. Western wall mafic rocks (W3) mostly contain more albite and less quartz than Eastern Wall mafic rocks, which may reflect the strong albitisation affecting the surrounding lithologies (mostly albitite).

Albitite (W1, W2) dominates in the Western Wall sequence. These are interbanded with, and grade into, metamafic rocks and may also grade into quartzite, and probably represent altered arenite with basaltic tuffaceous beds. Albitisation perhaps preferentially replaced more permeable zones, or it may have been structurally related. These rocks have some minor, patchy mineralisation and some very tourmaline-rich zones, but there is no clear relationship of either to the albitisation. The 'granitoid' described in ABM mine mapping does not appear to exist, and the coarse grained zones (W2) in these areas appear to represent late-stage recrystallised and quartz-carbonate altered albitite. The albitite is invariably brecciated, strongly veined and locally highly mylonitised and recrystallised. The Western Wall units may be transitional into the siliceous Mega Ramp Schist (Eastern Ahrberg Group?), but are more albitic. This sequence is thought to represent a highly albitised volcano-sedimentary sequence. There is no obvious relationship between albitisation, mineralisation and other forms of alteration, although carbonate alteration and weak tourmalinisation are very common in the albitite. Albitisation is a very typical wall-rock alteration in magnetite deposits of the iron-oxide-copper-gold (IOCG) style (Sillitoe, 2003).

The Eastern Wall mafic sequence is also dominated by metamafic volcanoclastic and/or lithic arenite sequences, and is similar to the mafic parts of the Host Sequence as well as the Western Ahrberg Group and Armstrong Creek units. It differs from the Ahrberg Group and Armstrong Creek units in mostly containing more abundant biotite, amphibole and epidote, with chlorite and muscovite less abundant, and may be of higher metamorphic grade. Some zones contain very abundant disseminated carbonate alteration (calcite and/or dolomite). This sequence is generally significantly richer in quartz, carbonate minerals and chlorite, and poorer in albite, amphibole and epidote than the Host Sequence mafic rocks.

The Armstrong Creek Formation contains a metamorphosed metamafic to quartz sandstone sequence with some minor mafic volcanoclastic beds and a talc-chlorite mylonitic zone suggesting a possible altered carbonate-rich mafic zone. There is some doubt as to the attribution of some of the rocks mapped, as this unit is north of the main pit.

The Armstrong Creek Formation and Ahrberg Group are petrologically similar, both comprising mostly siliceous metamafic tuff and/or tuffaceous sandstone

sequences, mostly altered and metamorphosed to the greenschist facies, but with some probable relict amphibolite and/or blueschist facies zones. The amphibole-rich rocks may represent mafic tuff, while the quartz-chlorite biotite and muscovite assemblages are inferred to represent sediments derived from reworked mafic tuffs, thus being more altered and weathered to clay prior to metamorphism. An alternative explanation is that they are more highly sheared and retrogressed, although their distribution does not particularly support this. These sequences were mostly poorly sampled and more detailed sampling may reveal some differences.

Original igneous rocks are represented only by sporadic altered metadolerite, or perhaps some metabasalt. They are relatively highly altered but only slightly deformed, so primary textures are reasonably well preserved. They mostly occur in the host sequence as small dykes or boudins up to a few metres across, and are fine to coarse grained or porphyritic, with some probable vesicular zones. They contain some biotite, indicating potassic alteration (this is also typical of IOCG magnetite deposits).

Mylonite and breccia are very common, but mostly occur in narrow zones (a few millimetres to a few metres wide), and are concentrated within the main host unit. They grade into mineralisation with increasing magnetite and pyrite contents. In some mylonites porphyroblastic albite can be seen to be replacing chlorite and contains lineated inclusions of amphiboles, showing albitisation is syn- or post-deformational.

The main host sequence comprises pods of massive to disseminated magnetite ores in an assemblage of mostly highly magnesian rocks including carbonate rocks, mafic rocks, and serpentine, amphibole and chlorite-rich lithologies.

Mafic rocks in the main host zone (H7) are very similar to the Eastern Wall and Western Wall mafic rocks, but are generally slightly mineralised, with minor disseminated magnetite and pyrite, and largely appear post or late syn-deformational. They are generally slightly richer in blue amphiboles, implying a higher metamorphic grade. Some brown cores in coarser amphiboles, with blue to green cores, may be primary amphibole grains.

The carbonate units include magnesite and dolomite-rich micritic to sparry sedimentary rocks, and grade into dolomitic quartzite and mafic schist. Most magnesite bodies are brecciated and partly dolomitised and the thinner units (up to one metre) are mostly almost totally dolomitised. There is commonly an early very fine-grained magnesite phase, mostly variably brecciated and altered to dolomite. Dolomite-rich units may be partly intermixed with chlorite, leucoxene, mica and other minerals that were probably derived from some intermixed sedimentary and mafic tuffaceous material. Serpentine, amphibole and talc-rich carbonate rocks appear to largely represent retrogressed magnesian skarns, although

some talc and amphiboles in these carbonate rocks appear to be primary. The pyroxenites are probably unretrogressed magnesian skarns, derived from siliceous dolomite. Talc-rich zones mostly form on the contacts of magnesite and silicate-rich rocks, and grade into mylonite.

## **Mineralisation and alteration**

The main ore mineralogy is very simple and consists of massive magnetite (the main ore), pyrite and minor hematite, apatite and chalcopyrite. These minerals are mostly disseminated to locally massive or in very minor veins, and texturally appear to be largely of replacive origin throughout various rock types, but are mostly hosted within breccia and mylonite dominated by carbonate minerals and Mg silicates. The apatite appears to be relatively early, but pre-dates magnetite and pyrite, which still formed in an early granulite-facies metamorphic event; the timing and origin are still under investigation. The mineralised rocks are typically magnetite and pyrite-rich breccias, rich in talc, serpentine and carbonate minerals, which largely suggest altered magnesian skarns in composition, although chlorite, sphene and rutile are locally abundant. This hybrid host rock may be due to both sedimentary intercalation and tectonic mixing. The magnetite in these rocks is usually highly brecciated, usually parting along zones of exsolved ilmenite. It is also commonly partly replaced by serpentine and other silicate minerals, and rarely also calcite. On a microscopic scale both magnetite and pyrite have mutual inclusions and similar textures, indicating co-recrystallisation and an equivalent deformation history, but pyrite zones may cross-cut magnetite on a large scale, perhaps indicating some pyrite of a later generation. There is little indication of the lamination usually found in exhalative banded iron formations, which are usually relatively thin and extensive. Tentatively, it appears that zones with mixed mafic and magnesite-dolomite beds were metamorphosed and tectonised forming mylonitic breccia zones which provided reactive and permeable horizons for magnetite mineralisation. A similar scenario was postulated for some IOCG-style magnetite deposits in metamafic breccias with carbonate zones in Sweden (Smith *et al.*, 2007).

The mineralisation thus apparently formed by complex sequences of processes including early metasomatism, several medium to high-grade metamorphic events and late-stage brittle deformation. The magnetite bodies may be boudinaged and locally upgraded by transposition in fold hinges, perhaps in a large fault melange originally containing a mixture of carbonate rocks, mafic rocks and minor siliceous sedimentary rocks. There is no evidence for the serpentinite and other Fe-Mg rich rocks to be of igneous origin. These tentative observations on the ore will be further investigated using geochemical results and other studies.

Potassic alteration is represented by extensive biotite, probably replacing earlier (pre-albite) amphibole in the mafic rocks in the host sequence, and the probable pre-existing biotite in much of the magnetite ore zone (now all altered to chlorite and other minerals).

Albitisation is indicated by the abundant albitites and also the albitisation in the Mega Ramp Schist and some mafic rocks in various parts of the sequence. Some of the blue amphiboles in the sequence are very sodic; some of this may be due to high-pressure metamorphism, but initial microprobe studies suggest some are more riebeckite-rich, suggestive of relatively low-pressure sodic alteration.

Magnesium alteration is extensive in the ore zones, and magnetite commonly appears altered to chlorite, antigorite and amphiboles; biotite is all altered to chlorite; and chlorite to serpentine and talc. Some amphibolitic and epidote alteration may indicate Ca-alteration (probably synchronous with Mg-metasomatism, i.e. calc-silicate alteration).

Pyritisation appears to be a late phenomenon in many of the local rocks, with cross-cutting textures, although much magnetite and pyrite are also co-recrystallised in many rocks (with mutual inclusion textures), suggesting two generations of pyrite.

Tourmalinisation is generally minor but almost ubiquitous in the mafic tuffaceous and metasedimentary rocks, but is almost absent in the skarns and carbonate rocks, except where there is a major tuffaceous component. It usually appears to be tectonically deformed in some rocks but is generally relatively late and does not appear to be related to magnetite or sulfide mineralisation, or other alteration

events. It may reflect magmatic alteration or B-rich evaporites in the sedimentary sequence, or alteration fluids derived from these.

'Devonian alteration zones' were mapped by ABM geologists in parts of the mine, especially in the Centre Pit, but these zones appear from our studies to represent albitite or quartz-rich meta-arenite, locally with minor disseminated pyrite, tourmaline and detrital muscovite, and show no definitive geochemistry or mineralogy to indicate a Devonian alteration event other than those affecting the rest of the mine sequence. The geochemistry of these rocks will be further studied and discussed in our next report.

Several metamorphic events can be identified, including an early granulite to hornfelsic facies metamorphism, a later blueschist facies deformation, at least two later greenschist facies penetrative events probably grading into mylonite, and late weak retrogressive events, unfoliated fault breccias and veins. The absolute timing of these events is highly conjectural. The host rocks are all locally overprinted with multiple-stage and mineralogically complex veins, fault breccias and mylonites, but this appears to be concentrated in the mixed carbonate-mafic units. Hydrothermal alteration is mainly characterised by the occurrence of secondary carbonate, albite, epidote, tourmaline and chlorite-rich zones and veins. Vein mineralisation is very minor but commonly includes minor pyrite, hematite and chalcopyrite, and rarely magnetite, plus a wide range of gangue minerals, mostly related to the local host rocks.

## Conclusions

In summary, the main magnetite mineralisation and alteration event was probably a high temperature metasomatism involving magnetite-pyrite replacement of reactive mafic/carbonate breccias. The ore and surrounding rocks have subsequently undergone multiple deformational and metamorphic events, including a high pressure–low temperature blueschist facies event followed by retrogression to lower greenschist facies. The original breccias contained early diagenetic magnesite and dolomite mixed with mafic volcanoclastic rocks, all probably metamorphosed at granulite facies to locally form pyroxene olivine amphibole biotite magnetite pyrite skarns and related rocks. Most of this granulite was retrogressed to serpentine amphiboles talc assemblages, subsequent to most mineralisation except weak veining. Part of the mineralisation (mostly lower grade material) is hosted in intercalated, weakly brecciated, mafic volcanoclastic rocks, intrusive dolerite bodies and possible basaltic lavas. The early metasomatic alteration events in the mine area include major albitisation and minor, but widespread, tourmalinisation, dominantly in the western sequence, plus extensive potassic alteration (forming widespread biotite, mostly in the host sequence), and probably some calc-silicate and magnesian alteration (also in the host sequence).

At this stage the relationship of these alteration events to magnetite formation is not totally clear, but intense K, Ca, Mg and Na alteration are characteristic of iron-oxide-copper-gold (IOCG)-style magnetite deposits, which look a very good fit for the Savage River mineralisation, especially the Cu-Au poor Kiruna sub-type (Sillitoe, 2003; Smith *et al.*, 2007). One difference is the carbonate-rich host, unusual in IOCG deposits (Bookstrom, 1995; Sillitoe, 2003), but Corriveau (2006) suggested that some iron skarns may actually be just a variant of IOCG deposits. The extensive Na-K Ca-Mg alteration, plus the Ti, V, Cu and P association with high-temperature, S-poor, iron oxide breccia deposits in volcano-sedimentary sequences, is certainly quite definitive for IOCG deposits.

This deposit style is probably generally vertically zoned, with the deeper, higher temperature zones being relatively poor in copper and gold and richer in magnetite and apatite (Sillitoe, 2003). The copper-magnetite deposits in the AMC (e.g. Alpine and Gourlays prospects; Bottrill and Taheri, 2006) are thus probably genetically linked, higher level parts of the same or related deposits. The Temma Fe-Cu-Pb-Zn deposits further west are probably also genetically related, despite lying in stratigraphically different rocks (Taheri and Bottrill, 2004). The copper vein deposits in the Balfour area are of uncertain origin (Taheri and Bottrill, 2004) but are associated with strong but enigmatic linear magnetic anomalies. It might be conjectured that the copper may be

remobilised from underlying, unexposed magnetite and Cu-bearing IOCG deposits. The gold deposits in the Savage River district (e.g. Specimen Reef and Golden Ridge goldfield; Bottrill and Taheri, 2006) are of uncertain genesis but probably lie within the Oonah Formation and thus may be of separate origin to the Savage River deposits (but perhaps derive from Devonian remobilisation of gold from underlying Au-bearing IOCG deposits?). Again our upcoming genetic studies may help resolve these relationships. IOCG deposits are generally thought to derive from mixed hydrothermal fluids with a mafic igneous and evaporite sources (Corriveau, 2006). This would fit with the suggestion of the Rocky Cape Group containing some evaporites (Bottrill, 2004; Everard *et al.*, 2007), and the presence of minor anhydrite veins in the SRM mine sequence (Bottrill, unpublished data). Alternatively, the Savage River magnetite deposits may be a hybrid of the two mineralisation styles (IOCG and iron skarns); our on-going studies should clarify these hypotheses.

### Further Work

The petrogenetic and ore genesis implications of this study will be discussed in more detail in a forthcoming MRT report, following more specific genetic, mineralogical and geochemical studies. A comparison of mineralisation between the Savage River mine and other magnetite deposits along the Arthur Lineament will also be included in our next report.

The Fulford Creek Schist needs to be examined and its relationship to other units, particularly the Mega Ramp Schist and Ahrberg Group, determined. The relationship between the Mega Ramp Schist and the Western Wall Sequence also needs some study.

The Armstrong Creek Schist needs study to resolve its relationships to the Ahrberg Group and Bowry Formation.

The genesis of the Bowry Formation sequence, particularly the mafic and 'ultramafic' rocks, needs study in less deformed and altered areas.

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[4 March 2008]



## Legend for Figures 2 to 7

### Rock Units from ABM Mapping

#### Disturbed

 Waste dumps; ore stockpiles

#### Tertiary

 Basalt (MBO-T)

 Soft mudstone; gravel (SAQ)

#### Devonian?

 Alteration (post-schistosity) comprising siderite-quartz-pyrite (ASQ)

#### Neoproterozoic

 Ahrberg Group. Very low grade metasediments and metabasalt

#### Cambrian metamorphic rocks (Neoproterozoic Protoliths?)

 Fulfords Creek Muscovite Schist. Includes minor metaconglomerate (SXW)

#### Bowry Creek Formation

 Mega Ramp Schist, mainly chlorite and chlorite-minor muscovite schist (OXH)

 Box Cut Carbonate Assemblage. Magnesite with interbedded chlorite schist (SMO)

 Dolomite-chlorite-muscovite schist

 Western Wall Banded Schist. Mainly mafic, subordinate felsic rocks

 Minor granitoid (ORF)

 Main Host Assemblage. Massive and schistose mafic rocks with minor talc schist and serpentinite

 Talc schist

 Ore, magnetite

 Eastern Wall Carbonate-Mafic Assemblage, chlorite carbonate schist

 Magnesite (SMO)

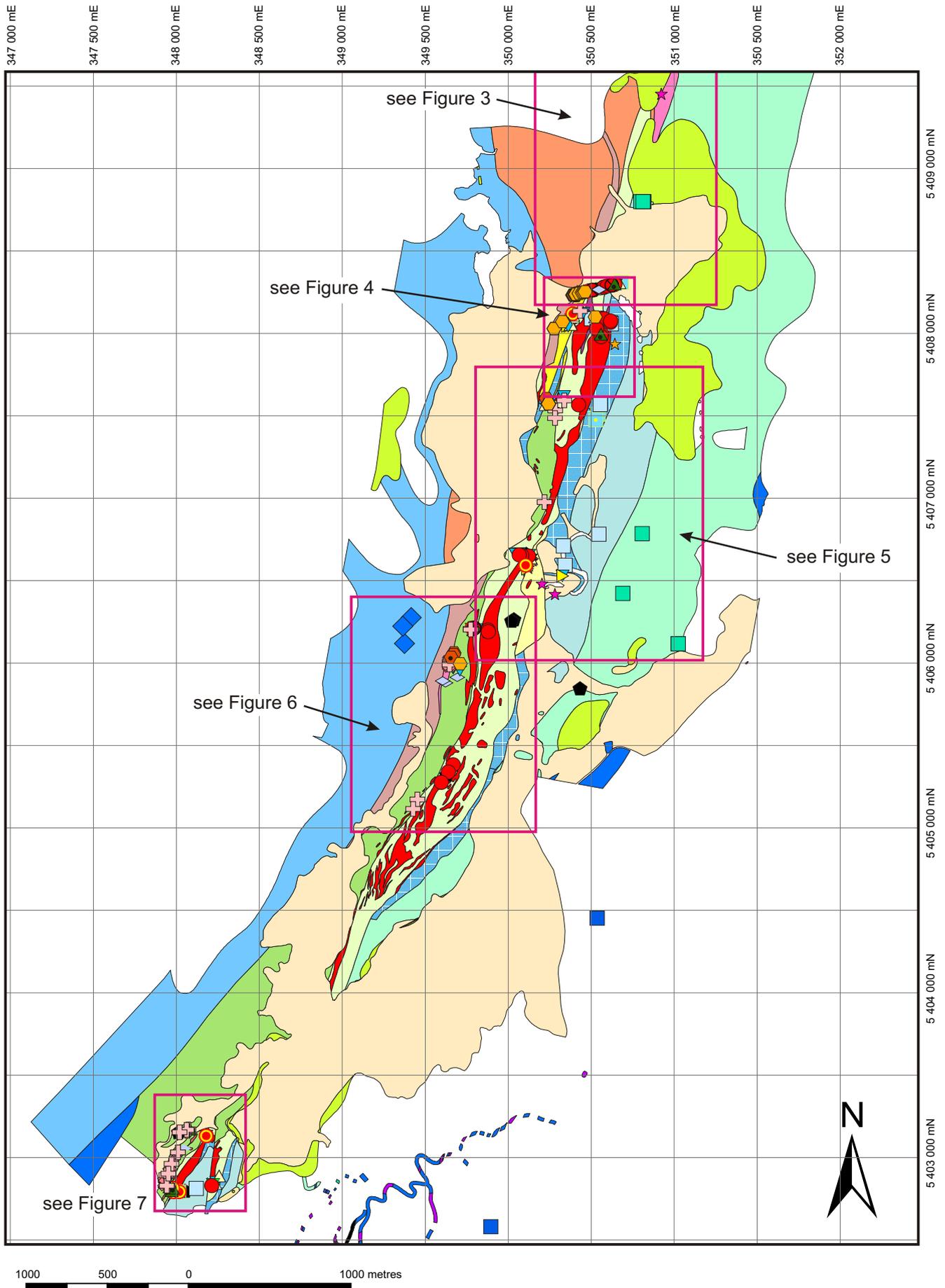
 Thin intervals of banded carbonate

 Armstrong Creek Mafic Schist. Subordinate massive, mafic rocks

 Oonah Formation. Muscovite-quartz + graphite schist (SXW)

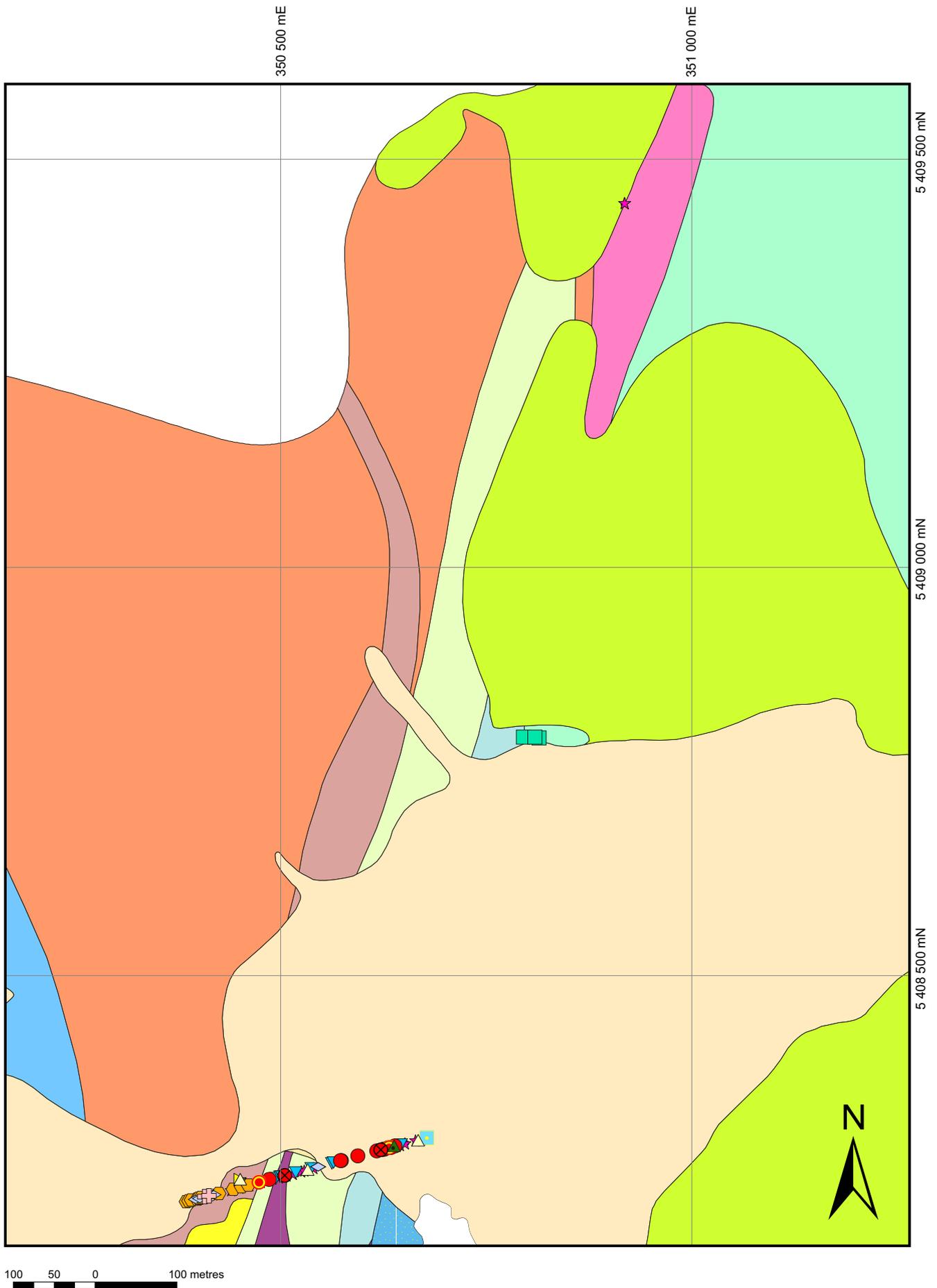
## Sample Lithologies

	Western Ahrberg Group (AG)		Ore (undifferentiated) (H2)
	Mega Ramp Schist (MR)		Serpentinite (H3)
	Muscovite schist zones (MRU)		Silicate-dolomite rocks (H4)
	Western wall banded schist (W)		Dolostone (H5)
	Albitite (fine grained) (W1)		Magnesite-stone (H6)
	Albitite (coarse grained) (W2)		Mafic meta-volcanic rocks (H7)
	Western wall mafic rocks (W3)		Eastern Wall Mafic Sequence (EW)
	Quartzite (W4)		Eastern Wall carbonate-rich zones (EWC)
	Quartz-amphibolite/pyroxenite (W5)		Armstrong Creek mafic schist (AC)
	Main Host assemblage (H)		Oonah Formation (OO)
	Amphibolite and pyroxenite (H1)		Intrusive rocks (ID)
	Apatite-rich rocks (H2ap)		Mylonite (Y)
	Pyrite-rich rocks (H2p)		Veins (V)

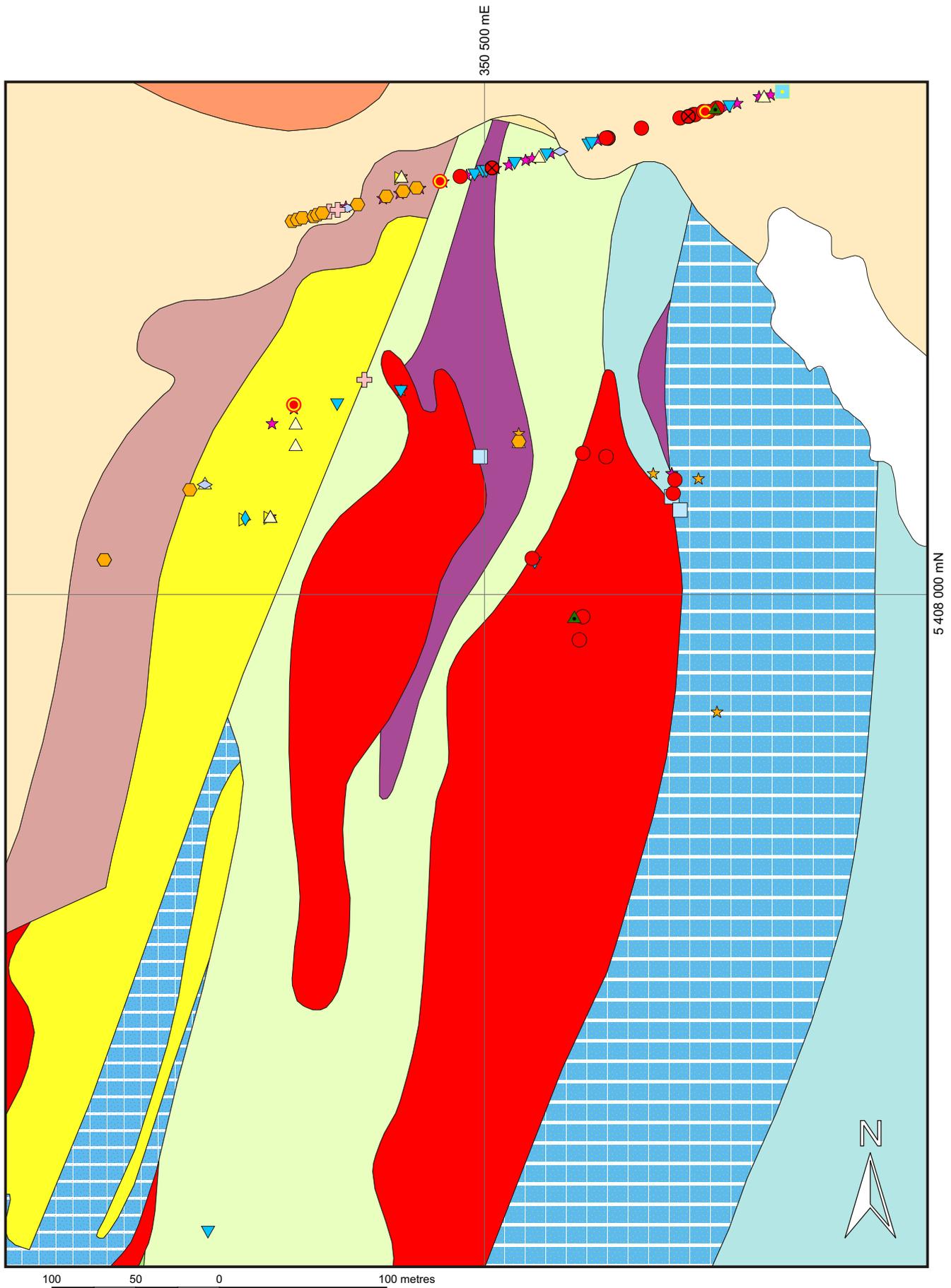


**Figure 2.**

*Geology map of Savage River mine region: 1:20 000 Scale (from Savage River Mines (ABM) base map), with sample sites. See pages 44/45 for rock unit and samples legends.*

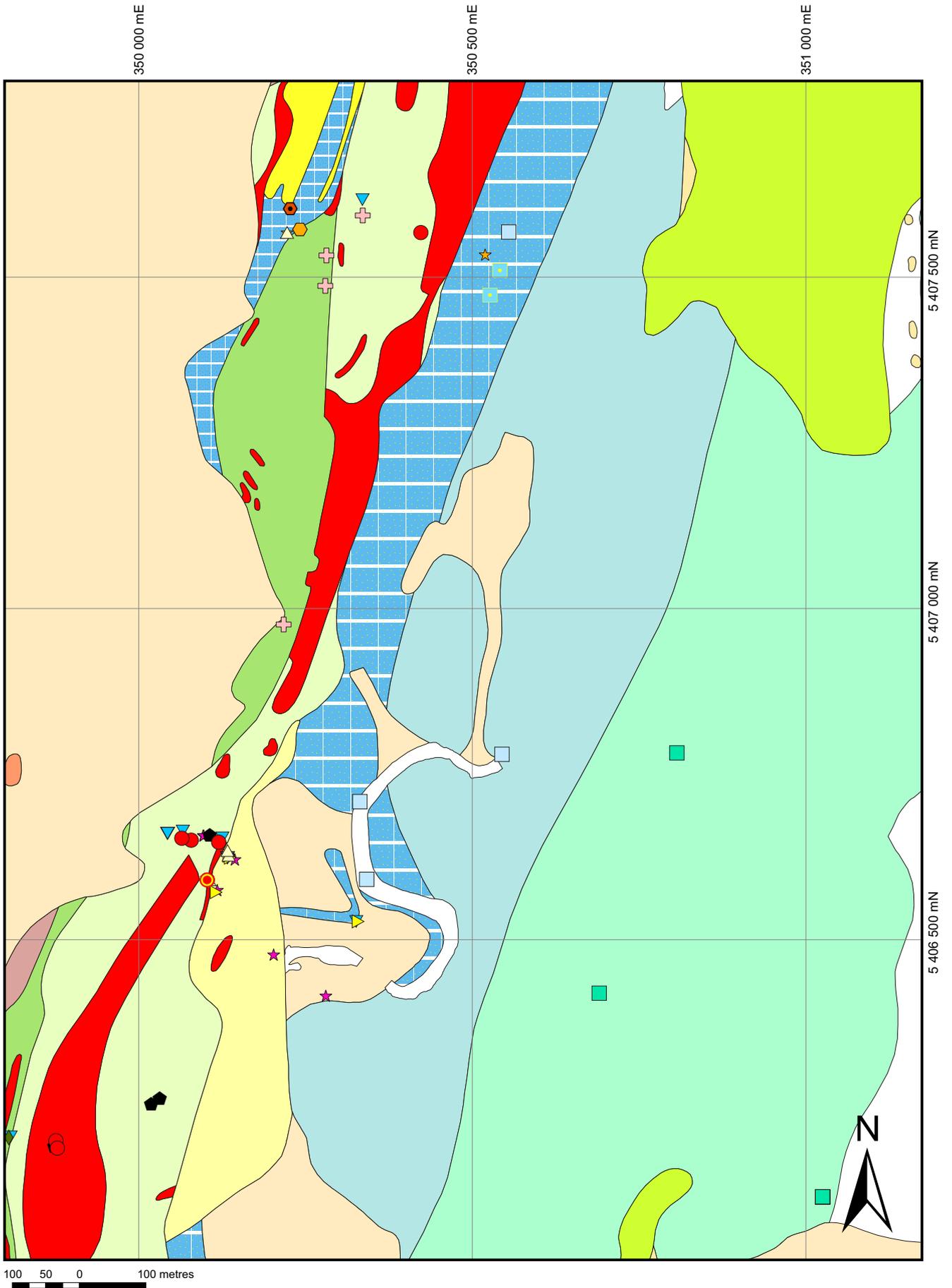


**Figure 3**  
*Sampling sites and geology, north of North Pit (on Savage River Mines base map).  
 See pages 44/45 for rock unit and samples legends.*

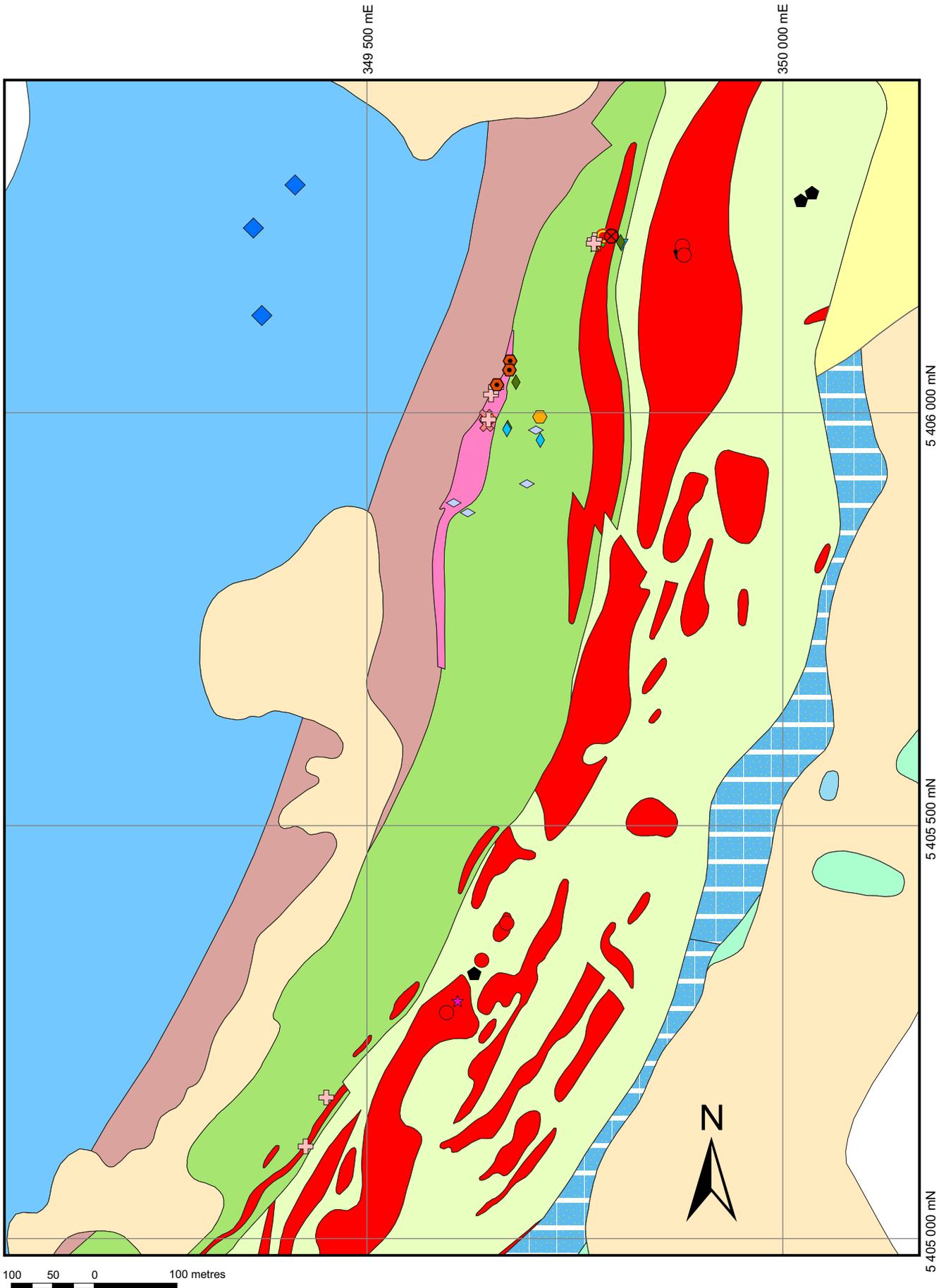


**Figure 4**

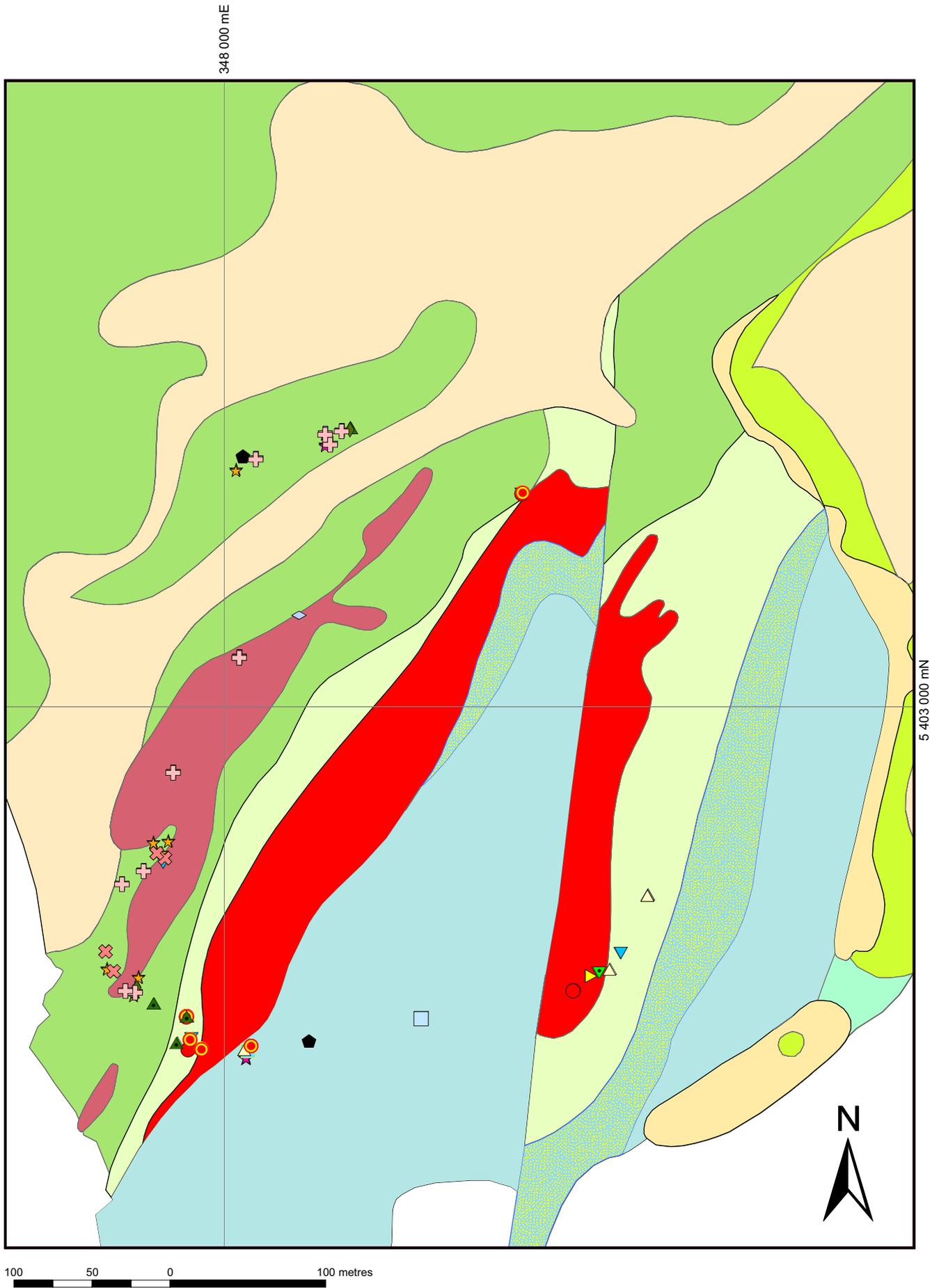
*Sampling sites and geology, North Pit (on Savage River Mines base map).  
See pages 44/45 for rock unit and samples legends.*



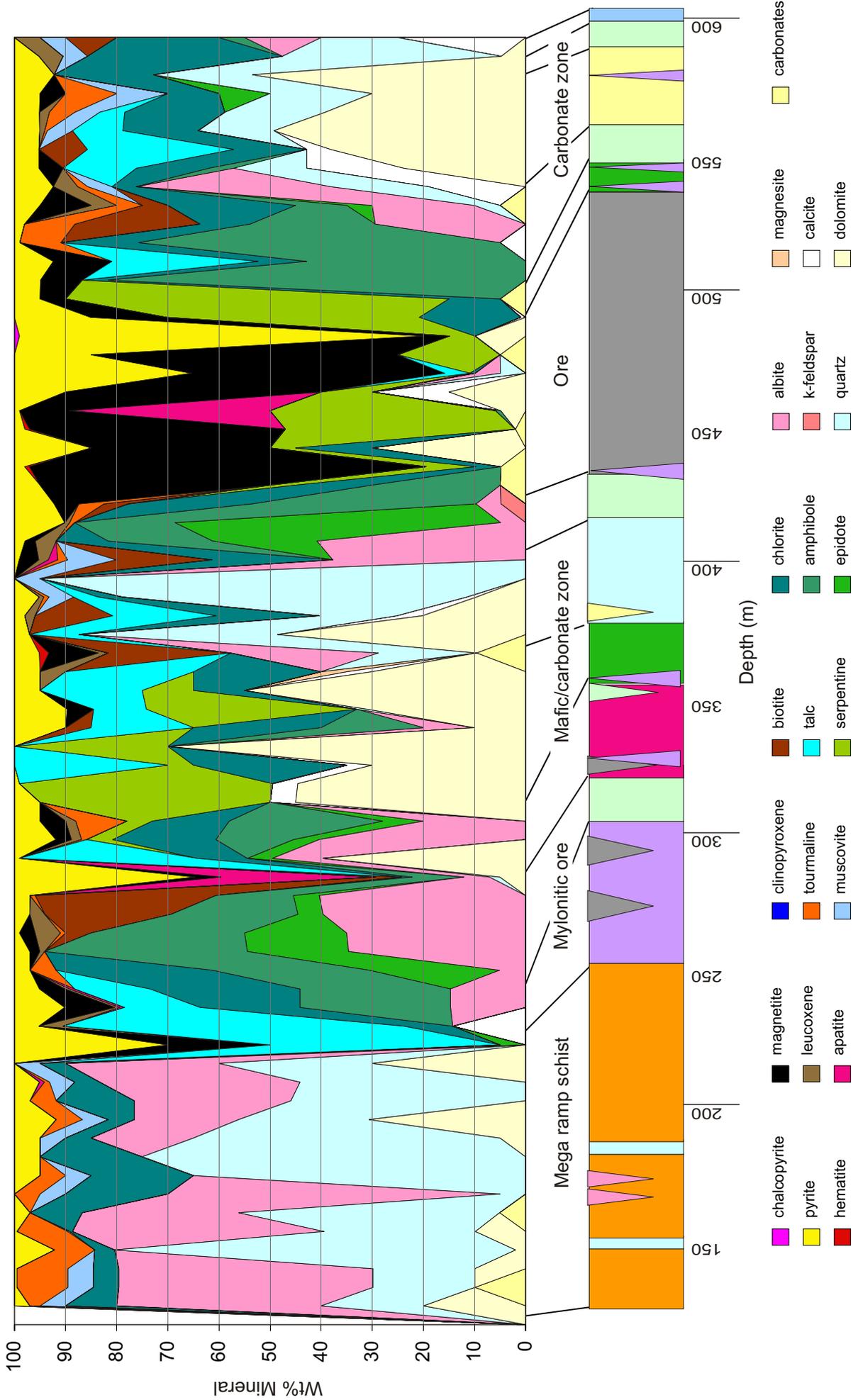
**Figure 5**  
*Sampling sites and geology, South Lens/Savage River Gorge East (on Savage River Mines base map).  
 See pages 44/45 for rock unit and samples legends.*



**Figure 6**  
*Sampling sites and geology, Centre Pit/Savage River Gorge West (on Savage River Mines base map).  
 See pages 44/45 for rock unit and samples legends.*



**Figure 7**  
*Sampling sites and geology, South Pit (on Savage River Mines base map).*  
*See pages 44/45 for rock unit and samples legends.*



**Figure 8**

*Mineralogical variation, drill hole NDDH601. Not to scale. See Appendix 4 for details of drill log.*

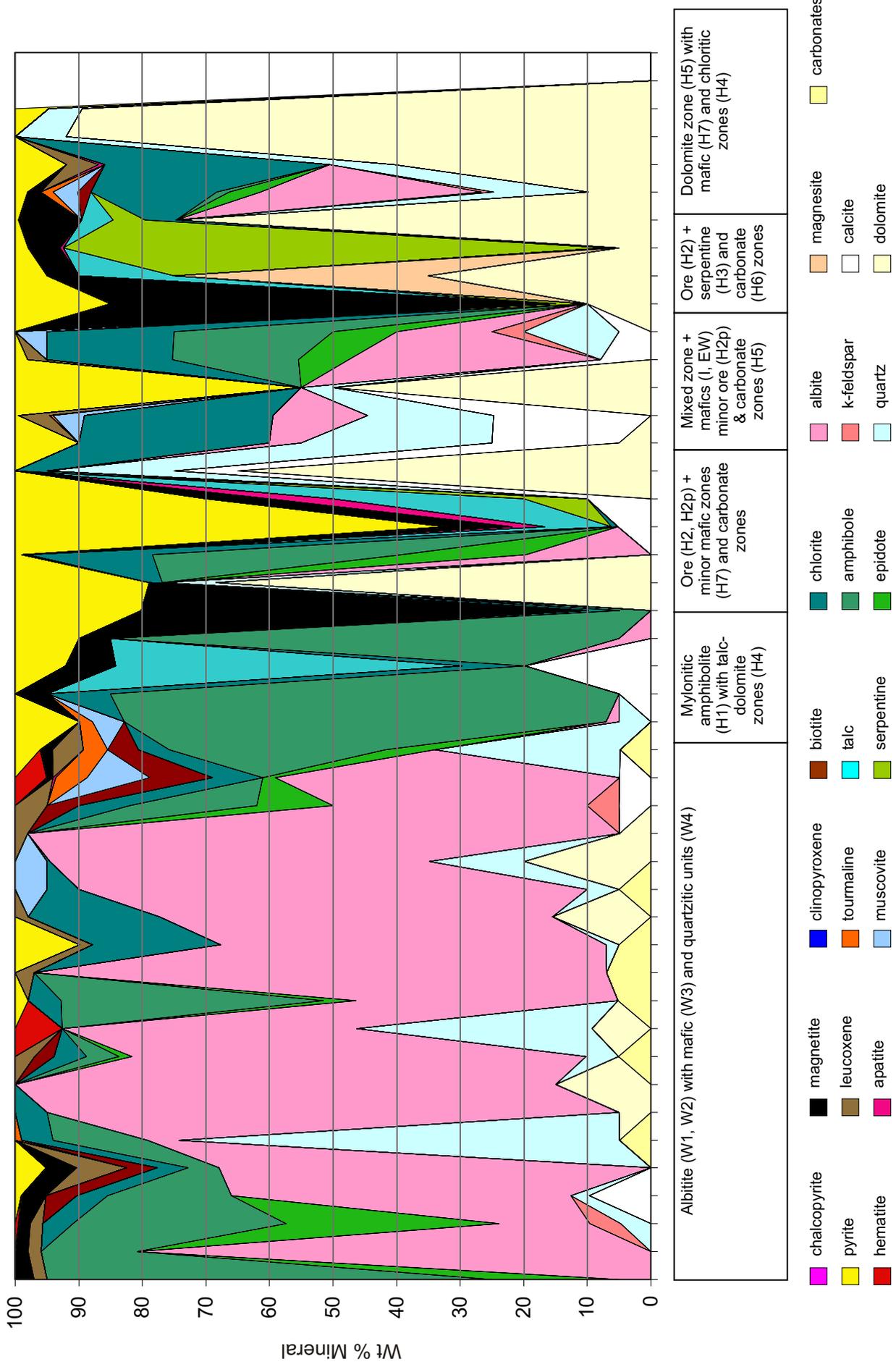


Figure 9

Mineralogical variation, South Pit Cross Section, west to east. Not to scale. Sample details are given in Appendix 9. See Table 1 for rock type details.

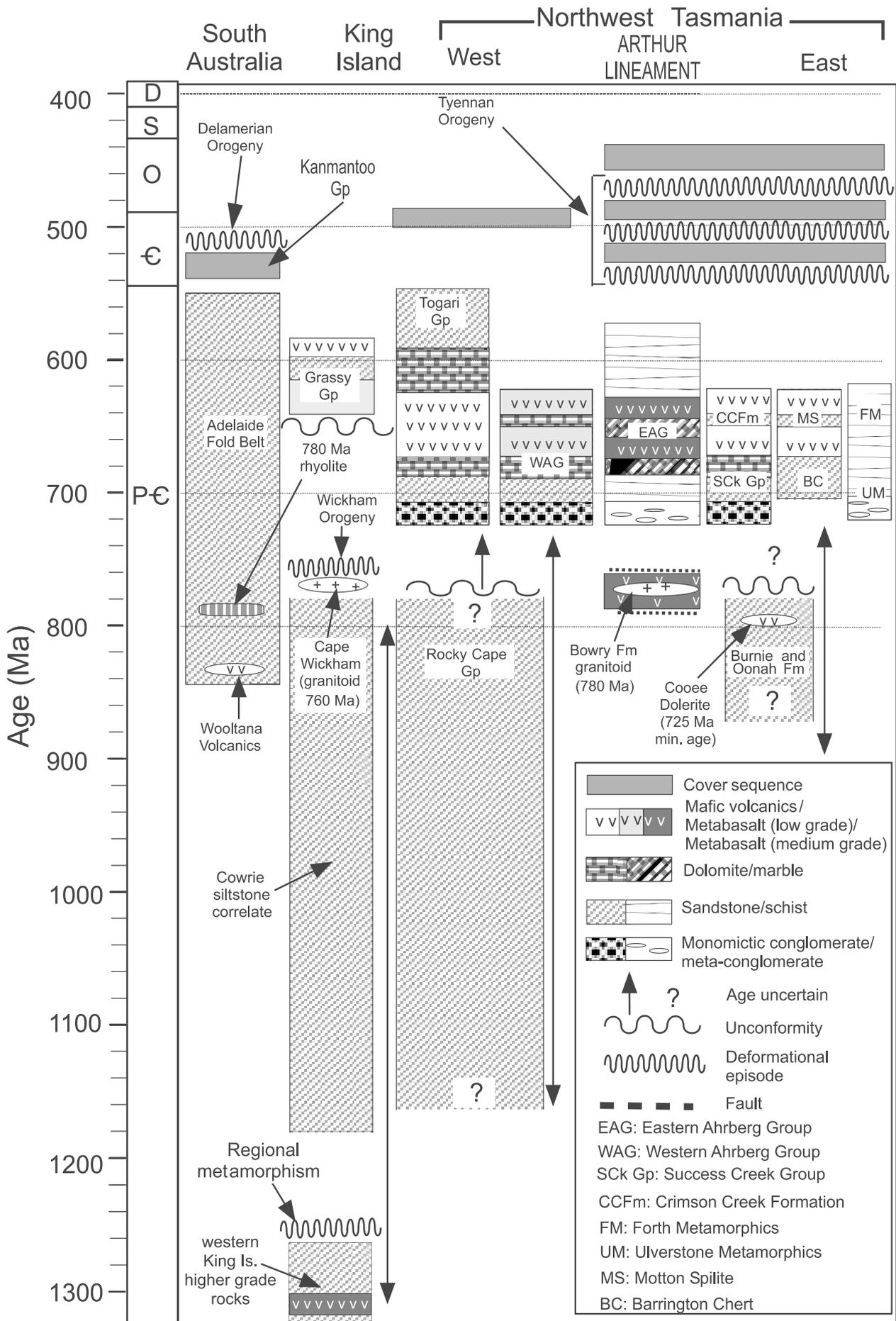


Figure 10

Time-Space diagram for the Savage River district (from Holm & Berry, 2002)