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PETROGRAPHY, CHLORITE GEOTHERMOMETRY, OXYGEN AND CARBON ISOTOPES AND FLUID INCLUSION STUDIES ON DRILL HOLES MXRD1 AND MC~~P~~D6, MT CATTLEY AREA.

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A REPORT TO BILLITON AUSTRALIA LTD.

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CONCLUSIONS AND RECOMMENDATIONS

1. Andesitic volcaniclastic wacke begins at 525.5m in Drill hole MXRD1 and at 674.2m in drill hole MC~~P~~DD6. In both cases the drill holes pass through aphyric rocks below to feldspar phyric above. It is valid to compare alteration effects in the two holes using these horizons as a reference.

2. There is a good agreement between chlorite and carbonate thermometry if a fluid with a $\partial\ ^{18}O$‰ value +2‰ is applied. This is based on fluid inclusion thermometry of a calcite with a measured $\partial^{18}O$ value.

3. Both drill holes show strong vertical temperature gradients, but temperatures in MCPD6 are consistently higher at the same inferred stratigraphic level compared with MXRD1. This is based on chlorite thermometry in apparently unmetamorphosed parts of vesicles and on oxygen isotope compositions of carbonates . The temperatures near the reference horizon in MXRD1 (525m) is about 125°C and in MCPD6 (672m) is about 180°C.

4. The alteration represents a subseafloor alteration a system with a steep thermal gradient and the data suggest the area is very prospective for VMS deposits. Drill hole MCPD6 would appear to be more proximal to a hydrothermal vent than MXRD1, but neither hole intersected a major footwall alteration system.

5. Jack (1989) recorded broad haloes (200m+) of Ba enrichment around Hellyer. Enrichment zones are present both in the footwall and hangingwall and are not uniformally developed around the orebody, but occur at a number of (more permeable?) horizons, particularly at the ore horizon and beneath the Que River Shale. In this regard the enrichment in Ba in the base of the feldspar phyric unit in MXRD1 recorded by Pemberton and Vicary is of considerable interest.
If Billiton decides to take up its option to joint venture on EL 14/85, detailed lithogeochemistry on MCPD6 should be done as a matter of priority. Future holes should be drilled to the Animal Creek Greywacke . Further geothermometric studies of this type should also be carried out as a continuing guide for exploration.

INTRODUCTION

Exploration Licence 14/85 is located in the Mt Cattley-Surrey Hill district, Norhtwest of Tasmania. The area has been explored for VMS type deposits and the present exploration is being undertaken by Outokumpu Exploration Australia in joint venture with Pancontinental Mining Ltd.
Andesitic volcanics below Tertiary basalt from drill holes MXRD1 and MCPD6 have been interpreted as correlates of the Que-Hellyer Volcanics which host the Que River and Hellyer massive sulphide deposits. The area is considered to have high prospectivity for VMS deposits.

This preliminary study was undertaken to investigate: (a) the alteration assemblages in the two drill holes, (b) The origin of fluid responsible for the alteration, (c) Whether the alteration in drill hole MCPD6 has been formed at higher temperature (i.e closer to a hydrothermal vent), and (d) the prospectivity of area for VMS deposits. It consists of sampling from drill holes MCPD6 and MXRD, petrographic, chlorite geothermometry, oxygen and carbon isotopes and fluid inclusion studies.

SUMMARY OF PETROGRAPHY FROM DRILL HOLES MCPD6 AND MXRD1

- A total of 10 polished thin sections were prepared for this work. In addition 19 thin sections from MXRD1 prepared for John Pemberton's regional study were examined briefly.
- The rocks in general consist of vesicular, feldspar phyric to aphyric andesites. They have been variably affected by carbonate , chlorite, silica and sericite alteration. However the original textures of the rocks have been preserved.

- Vesicles vary in size from <0.5mm to over 1cm in diameter . Minerals filling the vesicles include chlorite, carbonate, fine-grained quartz and mica (hydromuscovite?). The vesicles are normally filled with radiating blue chlorite with blue birefringence colours or carbonate and are rimmed with 1 or 2 minerals.

- Blue chlorite in vesicles commonly shows a rim of fine-grained green chlorite (reaction rim) or less commonly fuchsite. These reaction rims are syndeformational. However there is clear textural evidence that the "blue" chlorite is diagenetic hydrothermal.

- Carbonate in larger vesicles are commonly recrystallised; however, clear, unstrained, coarsely crystallised carbonate can also be observed.

- Fluid inclusions in recrystallised carbonates have been strongly affected by necking down and have migrated to micro-fractures and cleavages. This may indicate that no significant later hydrothermal (metamorphic) fluid has been introduced into the system. Consequently, the carbonates have probably preserved their original isotopic signatures.

- There is a change from aphyric andesite below a sedimentary unit, possibly correlated with the “mixed sequence” of the QHV to feldspar phyric andesite above this unit. However it should be noted that this is the reverse relationship to Hellyer. *Whole rock geochemistry may enable detailed correlations to be made.*

- Sulphides include minor to rare fine grains of pyrite and chalcopyrite. The sulphides appear to have been formed as a result of in situ sulfidation. Rocks from MXRD1 may have relatively less disseminated sulphides

- Many samples (Appendices 1,1a) have either chlorite or carbonate filled vesicles, necessitating an approach involving geothermometry on both minerals.

Preliminary Fluid Inclusion Study in Carbonate-Filled Vesicles, DDH MXRD1.

The purpose of this preliminary study is to use fluid inclusion filling temperatures as an independent geothermometer, to test how the data correlates with the chlorite geothemometry of Walshe (1986) and to constrain the $\partial^{18}O$ values of the diagenetic fluid to facilitate interpretation of temperature from calcite oxygen isotope data.

Five unpolished fluid inclusion sections were prepared from vesicular andesite at different depths to investigate the possible occurrence of primary fluid inclusions in carbonate vesicles. It was found that only sample MXRD1, 554.8m contains some rare, small (6 to 10um), primary-looking fluid inclusions.

The fluid inclusions are of two phase (vapour+liquid) with negative crystal shapes and vapour to liquid ratios of less than 0.1.

There are several generations (types) of carbonates in the rocks. However all of the late- formed carbonates are clear and appear to have been formed as a result of recrystallisation. The original (primary) fluid inclusions in these carbonates have gone through extensive necking down processes and have migrated to the cleavages and fractures, leaving the mineral without any fluid inclusions. This is significant , as it indicates that during deformation no or very little fluid was introduced to the system and consequently the oxygen isotope values of carbonates obtained from the vesicles have not greatly been affected by deformation. The homogenisation temperatures from 19 primary-looking fluid inclusions range from 115 to 141°C with 16 of the measurements between 115 to 129°C (average= 124±7.5°C, Figure 1, Appendix 2).

Freezing measurement of two fluid inclusions indicate freezing depression points of -6 to -8°C corresponding to about 9 and 11 equivalent wt% of NaCl in the solution.

The fluid inclusion homogenisation data shows a good agreement with the temperatures obtained from chlorite-filled vesicles of similar depth which give an average of 114°C.

The salinity of the fluid appears to be higher than average sea water of about 3.7w%.These higher salinities are however typical of massive sulphide forming fluids. Pisutha-Arnond and Ohmoto (1983) report a range of 3.5 to 8 wt% NaCl equivalent and significantly Khin Zaw (pers. Comm.) has established a salinity of around 10 wt% NaCl equivalent for the Hellyer ore forming fluid.

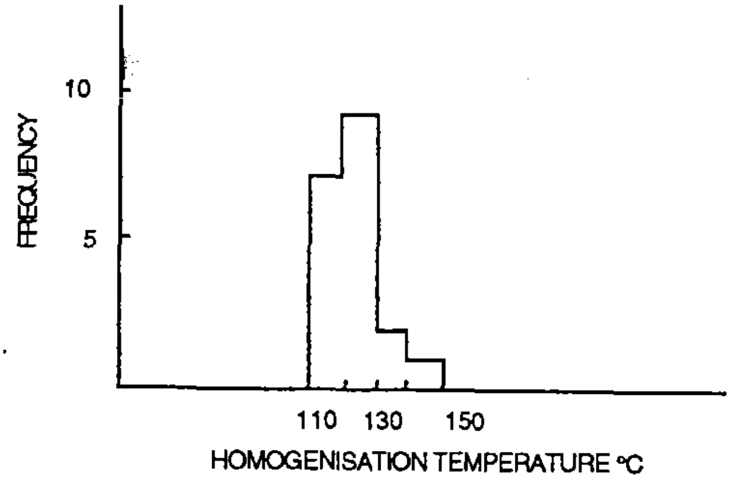

Figure 2. Frequency distribution of homogenisation temperatures from carbonate-filled vesicles, sample MXRD1, 554.8m.

Carbon and Oxygen Isotopes of Carbonate

The objects of this preliminary study are (1) to investigate the possible origin of fluid (i.e. se water vs metamorphic fluid) responsible for the alteration and (2) to use the oxygen isotope data as a thermometer and compare the results with those obtained through chlorite and fluid inclusion studies.

Twenty one carbonate samples from the carbonate-filled vesicles and carbonate veins from drill core MCPD6 and MXRD1 were analysed for carbon and oxygen isotope analyses. The results from this work, along with those obtained from drill core MCPD2 and MCPD3 (Green and Taheri, in preparation) are shown in Table The oxygen isotope values from 14 carbonate filled vesicles range from 13.1 to 24.5 ‰ with an average and standard deviation of 16.7±2.8‰. The oxygen isotope values of carbonate veins are slightly lower than those in vesicles showing an average and standard deviation of 14±2‰ (Table 1 , Figure 2).

The carbon isotope values of carbonate-filled vesicles show a relatively narrow range of 0.4 to 3.1‰ (average= 1.5±1.1‰) and are in general heavier than those obtained from the veins (average= -0.4±0.9‰).

The carbonates from veins were analysed to test whether they have been formed from the same fluid as those in vesicles. However the different isotope values of the veins may indicate different sources or temperatures of formation and are not discussed any further.

In general, the oxygen isotope values of the carbonates are higher than those reported from other Cambrian VMS deposits in western Tasmania (Khin Zaw and Large, 1990). However, the higher values may simply indicate lower formation temperatures rather than a different source of fluid. The overall low temperature of the alteration is supported by the temperatures obtained from fluid inclusions and chlorite compositions.

The temperature of carbonates in vesicles can be calculated by assuming that the oxygen isotope values of the fluid was close to seawater (0‰) and that the isotopic equilibrium existed between the carbonate and fluid. By using the isotopic fractionation factor of Friedman and O' Neil (1977), a temperature range of 45 to 144°C is obtained (Table 1). However, if it is assumed that the fluid inclusion data represent the average alteration temperature then values of around 2‰ are

Table 1. Carbon and oxygen isotope data from drill holes MXRD1 and MCPD6.

Sample no.	∂13C PDB	∂180 PDB	∂18OSMOW	T,∂18O=0	T,∂18O=1	T,∂18O=2
MCPD2 89.9(1)	0.47	-14.68	15.73	113	124	136
MCPD2 89.9(2A)	-0.76	-15.89	14.48	127	139	152
MCPD2 98.6	-1.78	-14.78	15.62	114	125	137
MCPD2111.7	-1.75	-14.61	15.80	113	123	135
MCPD2 112,2	-1.80	-16.03	14.34	129	141	154
MCPD2 114.5	-1.52	-14.80	15.61	114	125	137
MCPD2 117.1	-0.73	-14.65	15.76	113	124	135
MCPD3 107.2	-0.56	-16.22	14.14	131	143	157
MCPD3 109.4	-0.69	-15.95	14.42	128	140	153
MCPD3 111.4	-0.56	-16.04	14.33	129	141	154
MCPD3 112.9	-0.79	-15.94	14.43	127	140	153
MCPD3 113,5	0.60	-14.55	15.86	112	123	134
MCPD3 113.9	0.41	-14.03	16.40	106	117	128
MCPD3 115.5	-2.36	-12.85	17.62	95	104	114
MCPD3 117.2	-2.07	-16.18	14.18	130	143	156
MCPD3 117.5	-0.90	-12.02	18.47	88	96	106
MXRD1 400.7 ves	0.58	-10.21	20.33	73	81	89
MXRD1 421.4 ves	1.36	-13.36	17.09	100	110	120
MXRD1 474.1 ves	1.14	-6.11	24.56	45	51	57
MXRD1 530.5 ves	-0.42	-13.74	16.70	104	114	124
MXRD1 554.8 ves	-0.38	-13.76	16.67	104	114	125
MXRD1 576.5 ves	0.92	-14.55	15.86	112	123	134
MXRD1 386.2 vn	-1.08	-15.83	14.54	126	138	151
MXRD1 415.7 1 vn	0.13	-15.31	15.07	120	132	144
MXRD1 447.3 vn	0.58	-14.49	15.92	111	122	134
MXRD1 474.1 vn	0.64	-12.31	18.18	90	99	109
MXRD1 523.8 vn	-1.55	-15.96	14.41	128	140	153
MCPD6 446.1 ves	2.00	-14.34	16.08	110	120	132
MCPD6 528.7 ves	2.76	-15.35	15.04	121	132	145
MCPD6 536.8 ves	2.67	-15.92	14.45	127	139	153
MCPD6 547.4 ves	0.88	-13.50	16.95	101	111	122
MCPD6 548.1 ves	2.83	-14.22	16.20	108	119	130
MCPD6 585.9 ves	1.20	-17.27	13.06	144	158	173
MCPD6 628.3 ves	2.28	-14.94	15.45	116	127	139
MCPD6 628.3 ves	3.06	-15.13	15.26	118	129	142
MCPD6 438.0 vn	-1.42	-18.09	12.22	156	171	187
MCPD6 762.5 vn	-0.21	-17.52	12.80	148	162	177

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T,∂18O=3	∂13Cfl,O=0	∂13Cfl,O=1	∂13Cfl,O=2	∂13Cfl,O=3	M below QRS
149	-2.79	-2.22	-1.65	-1.08	
167	-3.31	-2.73	-2.17	-1.61	
150	-4.98	-4.41	-3.83	-3.27	
148	-5.05	-4.48	-3.91	-3.34	
169	-4.27	-3.69	-3.13	-2.57	
150	-4.71	-4.14	-3.57	-3.00	
148	-4.01	-3.44	-2.86	-2.30	
172	-2.91	-2.34	-1.78	-1.22	
168	-3.20	-2.63	-2.07	-1.51	
169	-3.02	-2.45	-1.88	-1.33	
167	-3.31	-2.74	-2.17	-1.61	
147	-2.74	-2.16	-1.59	-1.02	
140	-3.24	-2.66	-2.09	-1.52	
125	-6.71	-6.13	-5.56	-4.99	
171	-4.44	-3.87	-3.31	-2.76	
116	-5.73	-5.16	-4.59	-4.01	
98	-5.31	-4.74	-4.17	-3.60	-45.2
131	-2.68	-2.11	-1.54	-0.96	-65.9
64	-7.06	-6.52	-5.98	-5.43	-118.6
136	-4.24	-3.67	-3.09	-2.52	-175
137	-4.18	-3.61	-3.03	-2.46	-199.3
147	-2.42	-1.84	-1.27	-0.70	-221
166	-3.66	-3.09	-2.52	-1.96	-31
158	-2.75	-2.18	-1.61	-1.05	-60.2
146	-2.79	-2.22	-1.65	-1.08	-91.8
119	-4.03	-3.46	-2.88	-2.31	--118.6
168	-4.06	-3.48	-2.92	-2.36	-168.3
144	-1.46	-0.89	-0.32	0.25	-46
158	-0.11	0.47	1.04	1.60	-128.6
167	0.14	0.71	1.28	1.83	-136.7
133	-3.08	-2.51	-1.93	-1.36	-147.3
143	-0.70	-0.13	0.44	1.01	-148
190	-0.54	0.03	0.58	1.12	-185.8
153	-0.82	-0.25	0.32	0.89	-228.2
155	0.07	0.64	1.21	1.77	-228.2
206	-2.68	-2.13	-1.59	-1.06	-37.9
195	-1.80	-1.24	-0.69	-0.15	-362.4

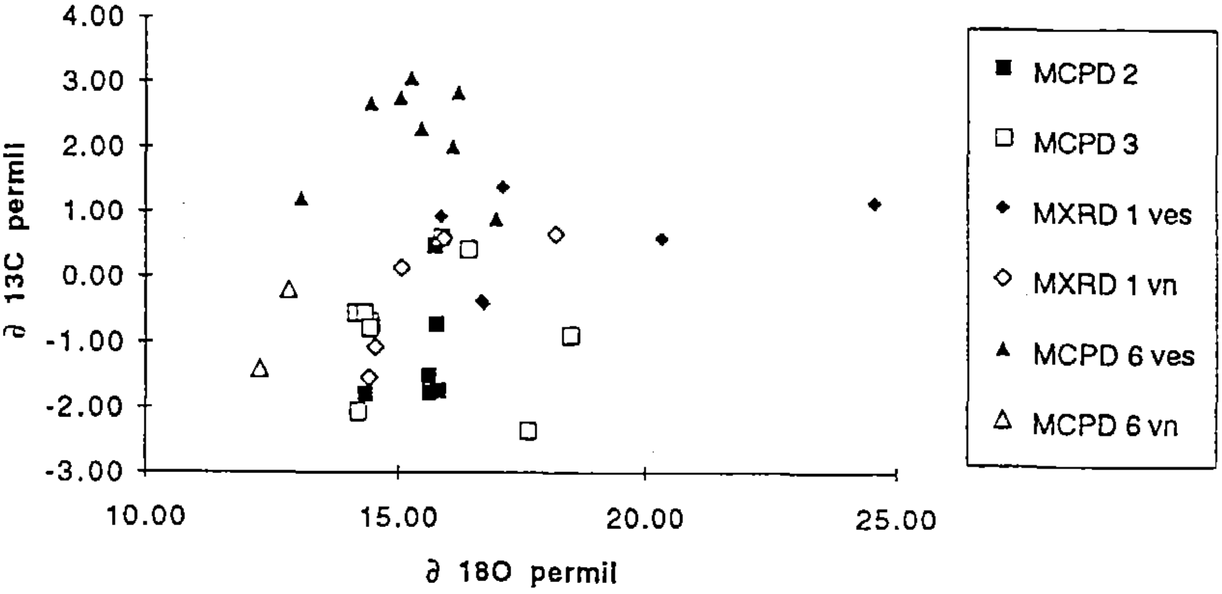

Figure 2. Carbon and oxygen isotopes data from drill holes MCPD2, MCPD3, MXRD1 and MCPD6.
ves= vesicles vn= Vein

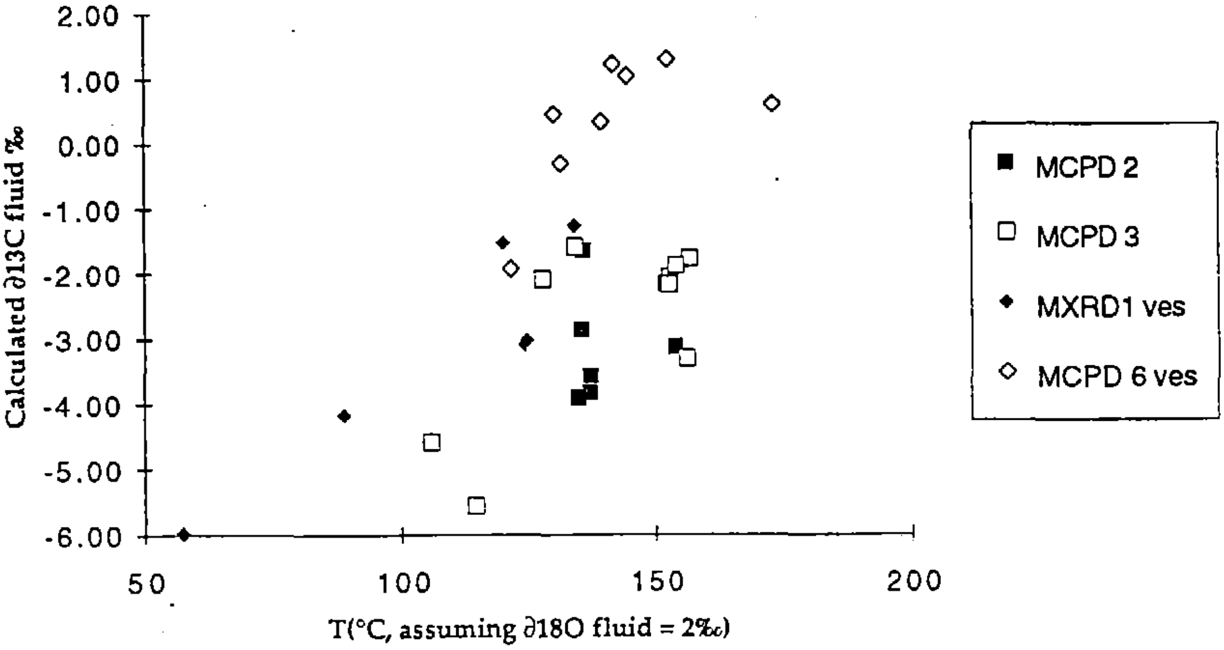

Figure 3. Calculated formation temperatures and $\partial^{13}C_{fluid}$ from carbonate-filled vesicles, assuming $\partial^{18}O_{fluid}$=2‰.

obtained for most of the samples. Figure 3 graphically shows the temperatures and $\partial^{13}C_{fluid}$ values, assuming $\partial^{18}O_{fluid}$=2‰.

One way to test the validity of the assumption of $\partial^{18}O_{fluid}$=0‰ is to calculate the carbon isotope value of fluid at the calculated temperatures, using the carbon isotope values of the carbonate temperature and the fractionation factors of Rye and Ohmoto (1979). If the values are close to 0‰, then the assumption of the seawater-dominated fluid may be justified. The calculated carbon isotope values of fluid are lighter than 0‰ and may indicate either or both of a contribution of magmatic CO_2 and CO_2 derived from oxidation of organic matter in sediments.

Table 1 shows the calculated temperatures for fluid with oxygen isotope compositions of 0,1 and 3‰ and also the carbon isotope values of fluid at calculated temperatures with the same oxygen values.

It should be emphasised that the oxygen isotope value of the fluid does not have to be 0‰ as some factors such water-rock ratios, mixing of sea water with hydrothermal fluid, isotopic exchange between the fluid and host rocks and also host rock type can effectively alter the original isotope values of the fluid. The variations observed in the oxygen isotope values may also be related to the replacement of early-formed carbonate by later carbonate of different origin. However this is not supported by some preliminary fluid inclusion petrography in which there is not sufficient evidence for introduction of externally-derived fluid at any great level during metamorphism (see fluid inclusion section for more detail).

Chlorite Geothermometry

The purpose of this study is to investigate whether the chlorite geothermometry method can be used in studying the original (i.e. Cambrian) hydrothermal alteration temperatures in drill holes MXRD1 and MCPD6 and how the results are compared with those obtained from carbonate oxygen isotope and fluid inclusion studies.

Three samples from drill hole MXRD1 and 5 samples from drill hole MCPD6 were selected for chlorite analyses. A total of 65 microprobe analyses were obtained from chlorite-filled vesicles and chlorite veinlets. The three main types of chlorites including blue, green and brown chlorites (birefringence colours) were analysed for this study.

Fine-grained green chlorite commonly occurs as rims on blue chlorite and appears to be an alteration product of the blue chlorite during metamorphism. This is clearly demonstrated in sample MXRD1, 547.4 in which the rims (i.e. fine-grained green chlorite) gave consistently higher, presumably metamorphic, temperatures (Appendix 3).

Only two brown chlorites from a chlorite veinlet were analysed from which only one high temperature of 367°C was obtained. Brown chlorite mainly occurs as syn-cleavage veinlets. Therefore, the results may represent metamorphic temperatures. This has already been investigated in some of the VMS deposits in western Tasmania (Green, pers. comm.).

Blue chlorite mainly occupies the centre of the vesicles and paragenetically appears to be the earliest formed chlorite type in the rocks. Only the undeformed and fresh-looking chlorites were used for the analyses.

The following are the results obtained from the analyses of the blue chlorites and the other two types are not discussed any further.

The temperatures obtained from chlorite in drill hole MXRD1 at depths of 386.2m, 530.5m and 547.4m are low and exhibit a range of 101 to 169°C. Fluid inclusion filling temperatures from carbonate-filled vesicles with an average temperature of 126°C at 554.8m is in a very good agreement with an average temperature of 114°C , obtained from chlorite temperatures at a depth of 547.4m. Sample MXRD1 386.2 is deformed and consequently the higher temperature of 169°C may indicate reequilibration of the chlorites at higher metamorphic temperatures.

The temperatures obtained from from drill hole MCPD6 show a wide range of 119 to 359°C and the temperatures appear to increase with depth and more importantly the results exhibit higher temperatures than those from drill hole MXRD1 at similar stratigraphic levels. For example, Polymict sedimentary horizon begins at 525m and 674.2m in drill holes MXRD1 and MCPD6 respectively. The average chlorite temperature in MXRD1 at 530m is about 114°C whereas that of MCPD at a depth of 671m is about 180°C (Fig. 4, Appendix 5).

The possible factors involved in creating the temperature gradient which appears to exist in drill hole MCPD6 and possibly in MXRD1 include

a)The subsurface granite at a depth of about 2km, indicated by interpretation of gravity data by Leaman and Richardson (1989). However, drill hole MXRD1 is located to the east of drill hole MCPD6 and the top of the granite dips to the west. There, if the underlying granite was the source of heat or alteration, then the rocks in drill hole MXRD1 should have been affected more intensely (i.e. show higher temperatures) at a similar RL. b) Regional metamorphism. There is no petrographic evidence for the rocks in one of the drill holes to be affected at higher temperatures than the other and c) subseafloor hydrothermal alteration with high thermal gradients. This seems to be the most likely mechanism explaining the steep temperature gradient in drill hole MCPD6.

In terms of the validity of the chlorite data, carbonate oxygen isotope results give similar temperatures to those obtained by chlorite geothemometry using an oxygen isotope value of 2‰ for the fluid (see appendices 2 and 3, also carbonate isotopes section for more detail). This along with the good agreement between the fluid inclusion data and chlorite temperatures indicate the reliability of chlorite geothermometry for these rocks.

Possible metamorphic overprint

Some chlorites, including the fine grained green chlorites in some vesicle rims and the brown chlorites give temperatures of about 360°C with the Walshe geothermometer calculated at liquid-vapour pressures. Whereas most calculated temperatures are lower with this model compared with the various empirical thermometers (Appendix 3), these chlorites, which show clear petrographic evidence of synmetamorphic formation, show higher temperatures. However, these chlorites are most appropriately calculated at likely the metamorphic pressure of about one kilobar. The metamorphic chlorites at this pressure give temperatures of 235 to 280°C which are consistent with the mineral assemblages in the rocks. One

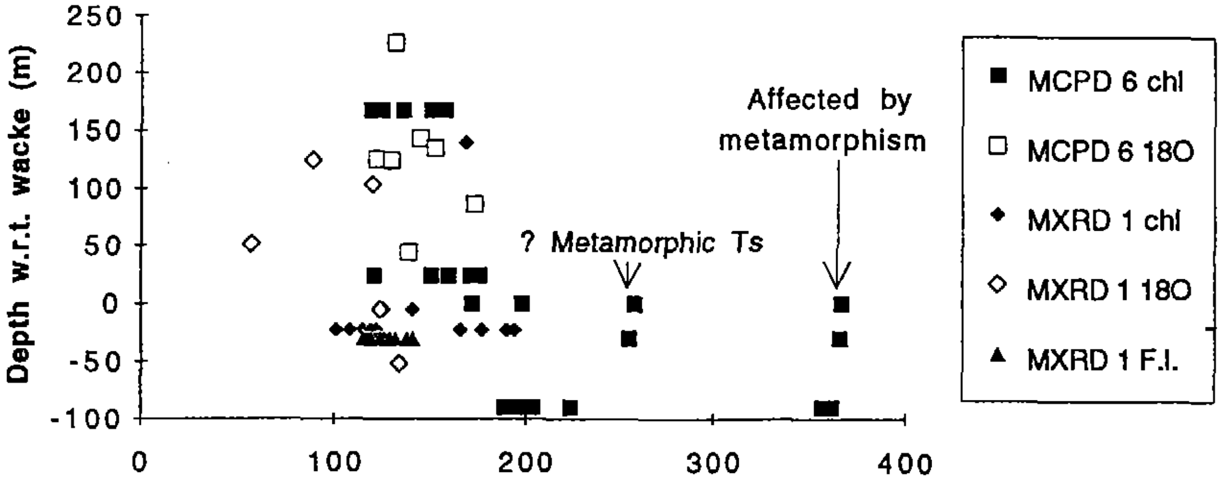

Fig. 4: Temperature data MCPD 6 and MXRD 1

chlorite from DDH MCPD6 @ 762.5m which gave the lowest temperature of 189°C at liquid-vapour pressure gave a one kilobar temperature of 205°C. This indicates that the chlorite geothermometry reflects the petrographic distinction between Cambrian hydrothermal and Devonian metamorphic chlorites.

One note of caution should be expressed however: some apparently hydrothermal chlorites from the deeper sections of DDH MCPD6 may not reflect true temperatures of hydrothermal alteration. This may be true of the 250°C+ temperatures calculated at 702m. At this depth there are none of the expected signs of such high temperature hydrothermal alteration (significant sulphide mineralisation etc.). The liquid-vapour temperatures of about 190 to 200°C reported at 762.5 m are believed to more accurately represent the highest alteration temperatures in this hole.

Conclusions from chlorite geothermometry

Compared on the basis of depth with respect to the clastic horizon separating the feldspar-phyric and aphyric units, the temperatures recorded from samples from DDH MCPD6 are consistently higher than those from MXRD1. This conclusion is compatible with the results from the ∂18O values of carbonates.

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APPENDIX 1 PETROGRAPHIC DESCRIPTIONS FROM DRILL CORE MCPD6 AND MXRD1.

MCPD6 504.7m

Grey Green Vesicular Feldspar Phyric Andesite.
The mineralogy of the rock has been affected by carbonate, silica, chlorite and sericite alteration. However the original texture has been preserved.
Vesicles range in size from less than 0.5mm to over 1cm and are filled with carbonate±chlorite±fine-grained quartz.
Carbonates are the most common alteration products and occur as (a) Late-formed veins and veinlets, (b) Replacing blue (interference colour) chlorite and phenocrysts, (c) major vesicle-filling and (d) rim on blue chlorite in the vesicles.
Quartz is mainly fine-grained (i.e. chalcedony) and occurs as (a) pseudomorph after feldspar, (b) vesicle-filling either as the only mineral or as a rim on blue chlorite and (c) small patches replacing the groundmass.
The fine-grained quartz appears to have been replaced with by carbonate and coarse-grained, mildly strained quartz. The latter, however is not common.
Based on interference colour there are three types of chlorites :
1) Blue chlorite which is the most common type and occurs as radiating form filling the vesicles.
2) Fine-grained green chlorite which occurs a rim on blue chlorite. The green chlorite appears to be the alteration product of the blue chlorite. This is shown by the corroded nature of the blue chlorite at the contact. Some vesicles are dominantly or even completely filled with green chlorite.
3) Brown chlorite occurs as a minor radiating mineral replacing blue chlorite.
Minerals of minor abundance include: a) Euhedral, disseminated chromite grains, up to 180µm and b) Leucoxene which occurs as dissemination throughout the rock and appears to be the alteration product of pre-existing titaniferous oxides.

Sulphides. Only few small (5 to 50µ) grains of pyrite, closely associated with vesicles are observed.

MCPD6, 585.9m

Strongly Vesicular Aphyric Andesite.

The rock is weakly cleaved and has been replaced by chlorite, carbonate, silica and sericite alteration.
Vesicles range in size from less than 0.5mm to several millimetres and are weakly flattened. The common order of minerals filling the vesicles from the centre outward is blue chlorite, mica (hydromuscovite?) and a thin (50um) chalcedony rim. There are also few larger vesicles filled with recrystallised carbonate, rimmed by chalcedony. Some vesicles are connected by thin (30µm) fine-grained quartz veinlets.
The nature and occurrence of the other hydrothermally-formed minerals (eg. carbonate, quartz and chlorite) are similar to those observed in sample MCPD6, 504.7m.

Sulphides. Fine (<5 to 100µm) disseminated pyrite and chalcopyrite are common (~0.1%). Pyrite is porous and one grain is characterised by sericite pressure shadows. The sulphides were probably formed by in situ sulphidation. The reasons are: (a) Fine grain size of the sulphides, (b) Close association of the sulphides and leucoxene and (c) lack of other sulphides such as sphalerite and galena.
MCPD6, 648.1

Strongly Vesicular Feldspar Phyric Andesite.

The rock has totally been replaced by carbonate, sericite, fine-grained quartz and chlorite.
Vesicles are up to 1cm in diameter, but are mostly smaller than 1mm. and are mainly filled either by dark grey-green fine-grained chlorite, rimmed by chalcedony or by carbonate. Carbonates filling larger vesicles are generally recrystallised and exhibit deformation twining. Some of the vesicles are connected by thin veinlets of chalcedony. Carbonate filling the vesicles can be of different generations. Few vesicles are filled by strained coarse-grained quartz and are rimmed by fine-grained dark blue chlorite. Carbonate veining is common. Minor, disseminated fine chromite also is also present.

Sulphides. Minor to rare disseminated pyrite and chalcopyrite. The sulphides range from 6 to 300µm, with the majority being between 6 and 60um.

MCPD6, 671.1

Feldspar Phyric Vesicular Andesite.

The rock is very similar to MCPD6, 648.1. The main differences are 1) Feldspars have only been partially replaced by sericite±carbonate±fine-grained quartz, 2) Quartz and carbonate in vesicles exhibit stronger recrystallisation, 3) The occurrence of deformed brown carbonate as veinlets and as rims on carbonate vesicles and 4) Alteration of some Fe-Mg minerals to brown chlorite.

Sulphides. Minor disseminated fine (5 to 90µm) grains of pyrite and rare chalcopyrite. The occurrence of a 1mm porous pyrite is an exception in size in this section.

MCPD6, 702m

Strongly Vesicular, Aphyric Andesite.

The rock has been affected by chloritisation of groundmass in less altered parts. More intensely altered sections are characterised by intense carbonitisation of the rock. Blue chlorite in vesicles is rimmed by chalcedony of different thicknesses and some vesicles have entirely been filled with chalcedony . Blue chlorite in the centre is commonly altered by fine-grained green chlorite from the rim inward and in some vesicles blue chlorite has completely been altered to green chlorite.
In general, larger vesicles are filled with recrystallised carbonate, however relics of primary growth zoning is still visible in some of the vesicles. Carbonate veining is abundant.

Sulphides. Rare disseminated fine (20to 90µm) grains of pyrite and chalcopyrite occur throughout the rock.

MCPD6, 762.5
Vesicular, Aphyric Andesite.

The rock has been affected by carbonate and sericite alteration with varying intensities. The vesicles are commonly filled by dark blue-grey chlorite and rimmed by fine-grained quartz. Fine-grained grey chlorite forms a thin rim around the blue chlorite, presumably a metamorphic effect. Minor brown chlorite is associated with recrystallised carbonate veins. It *also occurs as a rim to carbonate-filled vesicles.* Carbonate has commonly been recrystallised, although relics of colloform carbonate can still be seen in some of the carbonate vesicles. A 0.5cm vesicle is filled with mildly strained quartz and rimmed outward by radiating quartz (100µm), carbonate (120µm) , dark blue chlorite (15µm), carbonate (20µm) and chalcedony (15µm).

Sulphides. Rare pyrite as the only sulphide occurs as disseminated, very fine (2 to 10µm) grains in the rock.

MXRDI 386.2
Strongly Vesicular, Aphyric, Deformed Andesite.

The rock is cleaved and the vesicles have been flattened. Groundmass has been affected by chlorite, sericite alteration. Some vesicles contain radiating blue chlorite in the centre, rimmed outward with *hydromuscovite? and fine-grained chlorite to sericite.* Vesicles with dark grey-green chlorite can also been seen. Larger vesicles (greater than 3mm) are generally filled with deformed carbonate in the centre and are rimmed outward by hydromuscovite, fine-grained green chlorite and finally fine-grained quartz. There are also some vesicles which are filled with mica (hydromuscovite?) showing thin fine-grained chlorite rims.

Sulphides. Sulphides include rare, disseminated, fine (5 to 20µm) grains of pyrite and chalcopyrite.

MXRD1 474.1
Feldspar Phyric Andesite.

Rock has been affected by chlorite, sericite and carbonate alteration. Some feldspar phenocrysts have been partially altered to sericite. However chlorite alteration is dominant. Some phenocrysts have been totally altered to brown chlorite. The rock is low in vesicle concentration. Vesicles are filled with recrystallised, deformed carbonate. The rock has been cut by recrystallised carbonate veinlets.

Sulphides . No sulphides were observed.

MXRD1, 530.5m
Vesicular Aphyric Andesite.

Rock has been replaced by carbonate, *fine-grained* quartz, *sericite* and chlorite. Vesicles are mostly filled with carbonate, although some small (less than 0.5mm) vesicles are filled with fine-grained grey-blue chlorite rimmed by chalcedony. Carbonate veining is common.

Sulphides. Only few small (5µm) grains of pyrite can be seen in the section.

MXRD1 547.0
Vesicular, Aphyric Andesite.

The rock has partially been replaced by carbonate, chalcedony and sericite. Vesicles are up to 0.7cm in diameter, but are in general small (~2mm) They are mostly filled with radiating blue chlorite, rimmed by fine-grained quartz. Larger vesicles are filled with recrystallised, deformed carbonate and are rimmed outward by fine-grained dark blue-grey chlorite and chalcedony.

Sulphides. Only rare fine (20µm) grains of pyrite were observed.

Depth	Rock type	G'mass alteration	Fs; Fm alteration	Vesicles	Comments
379.5	Fs-fm Phyric	S cb, fs fresh	T: cb; T: chl		
397.18	"	Fresh	T: cb; T: chl+cb	One cb	
408.64	"	Local cb	T: cb+s+anh; T: chl	Cb-±qz-cb or cb	C.g. qz in vesicles
423.23	"	Fresh	Most fresh, some T:cb 1 cb+qz+sph. Fm T:chl	Chl-cb	Diss py,sph: most with late cb vnlets which are abundant.
439.7	"	Minor	T: s± cb	Most chl-cb	
452.56	"	"	T: cb or fresh; T:chl	Cb or chl	
460.5	"	W fs laths: s	VS-T:s; T: chl	Chl, some chl-fuchs-chl	
469.5	"	Fresh	VW:s; T: chl+qz±cb	Chl	
480.5	"	Minor	Variable to T: qz±cb; T:chl	Chl or cb, one chl-qz	
499.3	"	"	Variable to T: qz±cb	Chl or cb; cb strained	
509.93	"	"	T: cb+qz; T chl +qz	±chal-chl-qz or -cb	
525.1	"	VS: cb	T: cb± qz	Few generations of cb	
527.35	Polymict epic.	W fs laths: s	T: cb+qz, some inside clasts is fresh		Frags basalt, andesite, pumice, volc. qz etc.
538.68	"Aphyric"	Fs laths T: cb	Microphs T:qz+chl+cb	Cb or qz-chl-cb	
548.4	"	Fs laths VW:cb. Cb altern. in G'mass	?Microphs T: cb	Qz-chl-cb±qz	
557.16	"	Some fs unalt, some: cb		±Qz-chl-cb	
566.05	"	Fs laths S to T: cb±s G'mass cb altn.		Cb or qz or spectacular alternation of chalcedony-botryoidal cb-blocky qz	
574.64	"	Fs laths fresh or T:cb G'mass W: cb		Qz ± cb. One big ves. chal-cb-chal- dog tooth cb-massive sparry cb.	
596.8	"	Fs laths T:cb G'mass VS f.g. qz+cb			

Key to Appendix 1a

The table is a brief description of the alteration characteristics of a suite of thin sections from DDH MXRD1 prepared for John Pemberton's description of the drill hole. Many of the rocks display significant amounts of alteration albeit apparently low temperature. Of note is the preservation of anhydrite, a ubiquitous product of seawater alteration, but rarely preserved in ancient rocks, in altered feldspar from 408.64 m.

GROUNDMASS ALTERATION

Fresh refers to the lowest degree of groundmass alteration observed, namely unaltered albite laths set in very fine grained chlorite and opaques. Other abbreviations: VW= very weak, W= weak, S= strong, VS= very strong, T= total. Mineral abbreviations used are: s = sericite, chl= chlorite, fs= feldspar, qz= quartz, chal= chalcedonic quartz, anh= anhydrite, py= pyrite, sph= sphalerite. The abbreviation VW:s, for example refers the very weak studding of feldspar microlites with sericite.

FS; FM ALTERATION

This refers to alteration of feldspar phenocrysts (microph = microphenocrysts in the aphyric unit) and of ferromagnesian phenocrysts (fm). For example T: s±cb; T: chl means that feldspar phenocrysts are totally altered to sericite or carbonate or both and ferromagnesians are totally chloritised.

VESICLES

This refers to the zoning in vesicles from rim to core. For example ±qz-chl-cb means that quartz is present on the rims of some vesicles and passes inward to chlorite. The vesicles have carbonate cores.

APPENDIX 2: Homogenisation (Th°C) and Freezing (Tf°C) temperatres from Carbonate-filled vesicles, sample MXRD1, 554.8m.

SAMPLE NO.	Th°C	Tf°C
MXRD1, 554.8m	116	-
	115	-
	121	-
	126	-
	132	-
	126	-
	129	-8
	138	-6
	123	-
	118	-
	122	-
	141	-
	120	-
	118	-
	121	-
	121	-
	117	-
	124	-
	119	-

APPENDIX 3. CHLORITE COMPOSITIONS AND GEOTHERMOMETRY DATA

	A	B	C	D	E	F	G
1	PROJECT	SAMPLE	RING No	ANALYSIS	SiO2	TIO2	Al2O3
2	MT CATTLEY	MX1@386.1	23,1	1	28.93	0.03	16.33
3	MT CATTLEY	MX1@386.1	1	2	36.56	0.28	16.74
4	MT CATTLEY	MX1@530.5	24	1	30.21	0	14.75
5	MT CATTLEY	MX1@530.5	25	2	29.61	0.02	15.77
6	MT CATTLEY	MX1@530.5	26	3	29.87	0.01	15.73
7	MT CATTLEY	MX1@547.4	27,4	1cen,cg	30.73	0.05	15
8	MT CATTLEY	MX1@547.4	28,4	3rim,fg	29.04	0.02	18.85
9	MT CATTLEY	MX1@547.4	29,4	2rim,fg	27.82	0.02	19.13
10	MT CATTLEY	MX1@547.4	4	4cen,cg	30.82	0.02	14.77
11	MT CATTLEY	MX1@547.4	30,5	1cen	30.62	0.05	14.12
12	MT CATTLEY	MX1@547.4	30,5	2cen	30.88	0.02	14.2
13	MT CATTLEY	MX1@547.4	?		30.62	0.05	15.27
14	MT CATTLEY	MX1@547.4	31,?	2	30.598	0.05	15.1
15	MT CATTLEY	MX1@547.4	32,?	3rim	28.25	0	19.25
16	MT CATTLEY	MX1@547.4	?	4ditto	29.06	0.03	18.06
17	MT CATTLEY	MX1@547.4	33,3	1	30.87	0.01	14.5
18	MT CATTLEY	MX1@547.4	3	2ditto	30.46	0.01	15.18
19	MT CATTLEY	MX1@547.4	34,2	1	30.89	0.02	13.69
20	MT CATTLEY	MX1@547.4	35,2	2ditto	31.17	0.02	13.62
21	MT CATTLEY	MX1@547.4	1	1centre	30.77	0.05	14.6
22	MT CATTLEY	MX1@547.4	36,1	2rim	28.31	0	18.58
23	MT CATTLEY	MX1@547.4	1	3centre	30.53	0	14.37
24	MT CATTLEY	MC6@504.7	16,4	1	29.35	0.01	15.86
25	MT CATTLEY	MC6@504.7	17,3	1centre cg	29.99	0.09	14.56
26	MT CATTLEY	MC6@504.7	2	1	29.35	0.01	14.93
27	MT CATTLEY	MC6@504.7	19,2	2	28.73	0	15.45
28	MT CATTLEY	MC6@504.7	20,2	3	29.83	0.02	13.98
29	MT CATTLEY	MC6@504.7	21,1	1 cg	29.84	0	14.96
30	MT CATTLEY	MC6@504.7	1	2	30.18	0.01	14.06
31	MT CATTLEY	MC6@648.1	22,1	3	29.94	0.05	14.37
32	MT CATTLEY	MC6@648.1	1,1	1	29.25	0	17.03
33	MT CATTLEY	MC6@648.1	1	2	29.67	0.07	16.9
34	MT CATTLEY	MC6@648.1	1	3	30.01	0.01	16.769
35	MT CATTLEY	MC6@648.1	2,2	1	29.166	0	16.466
36	MT CATTLEY	MC6@648.1	3,2	2 cg	28.39	0	17.43
37	MT CATTLEY	MC6@648.1	2	3centre cg	29.03	0.03	17.12
38	MT CATTLEY	MC6@648.1	2	4 rim fg	29.87	0.05	15.91
39	MT CATTLEY	MC6@648.1	4,2	4 rim fg	30.42	0.03	17.27
40	MT CATTLEY	MC6@648.1	5,3	1centre cg	28.96	0	17.2
41	MT CATTLEY	MC6@648.1	6,3	2 rim fg	28.85	0.02	16.65
42	MT CATTLEY	MC6@648.1	3	2 rim fg	29.57	0	16.97
43	MT CATTLEY	MC6@648.1	8,4	1 fg	29.85	0	16.63
44	MT CATTLEY	MC6@671.7	37,1	1 fg	29.15	0	16.57
45	MT CATTLEY	MC6@671.7	1	2 fg	29.23	0.05	17.04
46	MT CATTLEY	MC6@671.7	38,4	1brown	28.37	0.04	19.03
47	MT CATTLEY	MC6@671.7	39,4	2brown	26.52	0.04	19.62
48	MT CATTLEY	MC6@671.7	40,2	1	27.95	0.01	17.34
49	MT CATTLEY	MC6@671.7	2	2	28.79	0.02	17.05
50	MT CATTLEY	MC6@702	41,2	1	25.96	0	20.8
51	MT CATTLEY	MC6@702	2	2	25.84	0	20.4

	A	B	C	D	E	F	G
52	MT CATTLEY	MC6@702	42,1	1	25.86	0.01	20.54
53	MT CATTLEY	MC6@702	1	2	26.24	0.01	20.62
54	MT CATTLEY	MC6@702	43,4	1	26.11	0	20.23
55	MT CATTLEY	MC6@702	4	2	26.66	0	19.89
56	MT CATTLEY	MC6@702	3	1	26.39	0.02	19.65
57	MT CATTLEY	MC6@702	3	2	26.35	0.04	19.66
58	MT CATTLEY	MC6@762.5	9,1	1	28.51	0	18.12
59	MT CATTLEY	MC6@762.5	1	2	27.9	0	17.79
60	MT CATTLEY	MC6@762.5	10,5	1centre	27.41	0.02	18.63
61	MT CATTLEY	MC6@762.5	11,5	2centre	28.07	0.03	17.59
62	MT CATTLEY	MC6@762.5	12,4	1centre cg	28.27	0	17.08
63	MT CATTLEY	MC6@762.5	13,4	2 rim fg	27.42	0	17.92
64	MT CATTLEY	MC6@762.5	14,2	1centre cg	27	0	19.18
65	MT CATTLEY	MC6@762.5	15,3	1centre cg	27.76	0.01	17.93

	H	I	J	K	L	M	N	O	P	Q
1	Cr2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Si	Al
2	0.04	22.49	0	18.74	0.11	0	0	0	6.06	4.032
3	0.13	20.91	0.04	13.74	0.1	0	0	0	7.24	3.907
4	0.07	25.65	0.02	17.55	0.04	0	0	0	6.301	3.625
5	0.02	26.29	0.05	16.49	0.04	0	0	0	6.196	3.888
6	0.01	26.26	0	16.97	0.04	0	0	0	6.202	3.849
7	0.01	24.61	0	18.16	0.03	0	0	0	6.339	3.646
8	0.04	25.715	0.05	14.83	0.14	0	0	0	6.01	4.598
9	0	26.74	0.03	13.84	0.09	0	0	0	5.875	4.761
10	0	24.82	0.002	18.26	0.05	0	0	0	6.355	3.589
11	0.03	24.27	0.05	18.4	0.03	0	0	0	6.392	3.474
12	0	25.76	0.02	18.2	0.04	0	0	0	6.375	3.455
13	0.006	24.9	0.007	17.74	0.05	0	0	0	6.321	3.715
14	0.003	24.69	0.021	17.89	0.06	0	0	0	6.329	3.682
15	0	27.3	0	14.41	0.14	0	0	0	5.86	4.705
16	0	25.56	0.033	15.49	0.14	0	0	0	6.038	4.424
17	0	24.42	0.05	18.67	0.05	0	0	0	6.369	3.526
18	0.024	24.78	0.06	17.79	0.03	0	0	0	6.311	3.707
19	0.033	24.41	0	18.66	0.03	0	0	0	6.44	3.362
20	0	24.29	0	18.52	0.02	0	0	0	6.494	3.345
21	0.03	24.31	0.033	18.32	0.06	0	0	0	6.373	3.563
22	0.008	25.86	0.043	14.69	0.12	0	0	0	5.952	4.604
23	0.02	23.94	0	18.6	0.05	0	0	0	6.366	3.532
24	0.03	25.67	0.02	17.09	0.08	0	0	0	6.141	3.912
25	0.03	26.21	0	17.12	0.05	0	0	0	6.296	3.603
26	0.04	26.86	0.01	16.08	0.01	0	0	0	6.245	3.745
27	0.04	28.34	0	15.61	0.04	0	0	0	6.102	3.867
28	0	28.3	0.03	15.97	0.02	0	0	0	6.33	3.498
29	0.01	26.86	0.08	16.93	0.04	0	0	0	6.238	3.685
30	0.04	27.26	0.07	16.99	0.04	0	0	0	6.33	3.475
31	0	27.2	0	16.39	0.03	0	0	0	6.324	3.578
32	0.01	21.66	0.12	19.42	0.15	0	0	0	6.025	4.135
33	0.01	21.9	0.06	19.79	0.15	0	0	0	6.049	4.059
34	0	21.9	0.07	20.06	0.18	0	0	0	6.083	4.006
35	0.03	21.49	0.12	19.54	0.16	0	0	0	6.056	4.03
36	0.04	21.03	0.05	18.7	0.23	0	0	0	5.96	4.312
37	0.02	21.19	0.08	19.17	0.17	0	0	0	6.024	4.188
38	0	21.42	0.13	16.86	0.21	0	0	0	6.369	3.997
39	0.02	21.77	0.09	19.27	0.18	0	0	0	6.143	4.111
40	0	22	0.03	19.38	0.14	0	0	0	5.971	4.181
41	0.05	21.68	0.03	19.18	0.18	0	0	0	6.021	4.095
42	0.04	22.13	0.12	19.47	0.13	0	0	0	6.046	4.089
43	0	20.93	0.09	20.03	0.15	0	0	0	6.114	4.016
44	0.05	23.29	0.02	18.64	0.14	0	0	0	6.043	4.048
45	0.05	23.61	0.12	18.63	0.18	0	0	0	6	4.119
46	0	23.71	0.1	16.98	0.17	0	0	0	5.848	4.623
47	0	24.87	0.06	16.97	0.15	0	0	0	5.538	4.827
48	0.05	23.7	0.05	17.46	0.13	0	0	0	5.9	4.313
49	0.03	23.48	0.05	18.09	0.14	0	0	0	5.989	4.181
50	0.02	28.5	0.06	12.83	0.1	0	0	0	5.513	5.206
51	0.04	29.29	0.1	12.86	0.06	0	0	0	5.497	5.116

	H	I	J	K	L	M	N	O	P	Q
52	0.08	29.14	0.12	13.03	0.08	0	0	0	5.482	5.131
53	0.04	28.75	0.1	12.55	0.1	0	0	0	5.569	5.158
54	0	28.87	0.09	12.94	0.07	0	0	0	5.556	5.075
55	0	28.45	0.08	13.12	0.09	0	0	0	5.654	4.973
56	0.02	28.65	0.09	13.48	0.08	0	0	0	5.607	4.921
57	0	28.09	0.07	13.45	0.03	0	0	0	5.625	4.948
58	0	26.54	0.16	16.52	0.14	0	0	0	5.863	4.391
59	0	26.11	0.07	16.32	0.11	0	0	0	5.848	4.394
60	0	26.1	0.12	15.76	0.13	0	0	0	5.756	4.61
61	0	25.91	0.04	16.22	0.07	0	0	0	5.898	4.358
62	0	25.1	0.06	16.93	0.09	0	0	0	5.947	4.235
63	0	25.78	0.09	16.32	0.1	0	0	0	5.79	4.459
64	0.03	26.68	0.1	15.48	0.11	0	0	0	5.663	4.74
65	0	26.59	0	16.57	0.05	0	0	0	5.791	4.409

CattleyChlorite Data.5

	R	S	T	U	V	W	X	Y	Z
1	Fe	Mn	Mg	Cr	Ti	Summe	Al4	VAC	Fe/Fe+Mg
2	3.939	0	5.849	0.007	0.01	19.92	1.94	0.084	0.402
3	3.464	0.01	4.055	0.02	0.04	18.755	0.76	1.245	0.461
4	4.474	0.0037	5.457	0.011	0	19.881	1.699	0.119	0.451
5	4.601	0.0094	5.1435	0.01	0	19.855	1.804	0.145	0.472
6	4.559	0	5.25	0.002	0	19.871	1.798	0.129	0.465
7	4.245	0	5.583	0.002	0.01	19.829	1.661	0.171	0.432
8	4.45	0.009	4.5735	0.007	0	19.684	1.99	0.3164	0.493
9	4.722	0.005	4.357	0	0	19.742	2.125	0.258	0.520
10	4.28	0	5.611	0	0	19.848	1.645	0.152	0.433
11	4.238	0.008	5.727	0.005	0.01	19.86	1.608	0.14	0.425
12	4.448	0.004	5.6	0	0	19.894	1.625	0.106	0.443
13	4.298	0.001	5.458	0.001	0.01	19.813	1.679	0.187	0.441
14	4.271	0.004	5.514	0.001	0.01	19.822	1.671	0.178	0.436
15	4.736	0	4.456	0	0	19.788	2.14	0.212	0.515
16	4.442	0.006	4.799	0	0.01	19.744	1.962	0.256	0.481
17	4.213	0.0088	5.739	0	0	19.867	1.631	0.133	0.423
18	4.294	0.011	5.496	0.004	0	19.832	1.689	0.168	0.439
19	4.255	0	5.799	0.005	0	19.872	1.56	0.128	0.423
20	4.233	0	5.752	0	0	19.83	1.506	0.17	0.424
21	4.211	0.006	5.657	0.005	0.01	19.836	1.627	0.164	0.427
22	4.547	0.008	4.605	0.001	0	19.745	2.048	0.255	0.497
23	4.174	0	5.781	0.003	0	19.867	1.634	0.133	0.419
24	4.49	0.004	5.329	0.005	0	19.9	1.859	0.1	0.457
25	4.601	0.0005	5.355	0.005	0.01	19.886	1.704	0.114	0.462
26	4.78	0.0009	5.099	0.006	0	19.879	1.755	0.121	0.484
27	5.033	0	4.942	0.007	0	19.961	1.898	0.039	0.505
28	5.023	0.006	5.052	5E-04	0	19.918	1.67	0.082	0.499
29	4.696	0.014	5.275	0.001	0	19.919	1.762	0.081	0.471
30	4.783	0.012	5.313	0.006	0	19.928	1.67	0.072	0.474
31	4.804	0	5.161	0	0.01	19.88	1.676	0.12	0.482
32	3.73	0.02	5.961	0.001	0	19.907	1.975	0.093	0.385
33	3.734	0.011	6.013	0.001	0.01	19.91	1.951	0.09	0.383
34	3.712	0.012	6.059	5E-04	0	19.913	1.917	0.087	0.380
35	3.732	0.021	6.048	0.004	0	19.927	1.944	0.073	0.382
36	3.693	0.009	5.85	0.007	0	19.881	2.04	0.119	0.387
37	3.677	0.014	5.929	0.003	0.01	19.876	1.976	0.124	0.383
38	3.819	0.024	5.358	7E-04	0.01	19.623	1.631	0.377	0.416
39	3.677	0.016	5.801	0.004	0	19.795	1.857	0.205	0.388
40	3.794	0.005	5.955	0	0	19.938	2.029	0.062	0.389
41	3.785	0.005	5.968	0.009	0	19.925	1.979	0.075	0.388
42	3.783	0.02	5.934	0.006	0	19.907	1.954	0.093	0.389
43	3.586	0.015	6.114	0	0	19.878	1.886	0.122	0.370
44	4.037	0.003	5.76	0.008	0	19.93	1.957	0.07	0.412
45	4.049	0.021	5.6952	0.008	0.01	19.934	2	0.066	0.416
46	4.087	0.018	5.218	0	0.01	19.835	2.152	0.165	0.439
47	4.342	0.011	5.282	0	0.01	20.04	2.462	-0.04	0.451
48	4.184	0.009	5.494	0.009	0	19.938	2.1	0.062	0.432
49	4.086	0.009	5.61	0.006	0	19.914	2.011	0.086	0.421
50	5.063	0.011	4.062	0.004	0	19.882	2.487	0.118	0.555
51	5.212	0.018	4.077	0.007	0	19.941	2.503	0.059	0.561

	R	S	T	U	V	W	X	Y	Z
52	5.165	0.022	4.115	0.013	0	19.946	2.518	0.054	0.557
53	5.104	0.018	3.969	0.007	0	19.847	2.431	0.153	0.563
54	5.139	0.016	4.105	0	0	19.906	2.444	0.094	0.556
55	5.048	0.014	4.15	0	0	19.859	2.346	0.141	0.549
56	5.09	0.017	4.269	0.004	0	19.928	2.393	0.072	0.544
57	5.015	0.013	4.281	0	0.01	19.895	2.375	0.105	0.539
58	4.564	0.029	5.065	0	0	19.941	2.137	0.059	0.474
59	4.577	0.013	5.098	0	0	19.955	2.152	0.045	0.473
60	4.583	0.021	4.933	0	0	19.936	2.244	0.064	0.482
61	4.553	0.008	5.081	0	0.01	19.918	2.102	0.082	0.473
62	4.415	0.011	5.308	0	0	19.936	2.053	0.064	0.454
63	4.554	0.016	5.139	0	0	19.98	2.21	0.02	0.470
64	4.678	0.018	4.837	0.005	0	19.965	2.337	0.035	0.492
65	4.64	0	5.152	0	0	20.003	2.209	-0.003	0.474

CattleyChlorite Data.5

	AA	AB	AC	AD	AE	AF	AG
1	T L-V	FO2 L-V	T 1KB	FO2 1KB	T CATAL	T catal new	T CATVAC
2	169	48.67			223	250	266
3					98	60	69
4	126	57.1			198	212	260
5	140	54.51			209	229	255
6	141	54.33			208	228	258
7	122	56.8			194	205	251
8	166	49.9			229	258	226
9	190	48			243	280	236
10					192	203	254
11	115	59.2			188	197	256
12					190	200	262
13					196	208	248
14	122	57.7			195	207	250
15	194	48.5			245	283	244
16					226	254	236
17	119	58.2			191	201	257
18					197	210	251
19	108	60.6			183	189	258
20	101	62.1			177	181	251
21					190	200	252
22	177	48.3			235	268	237
23					191	201	257
24	151	52.4			215	237	263
25	125	57.41			198	212	260
26					204	221	259
27	158	51.84			219	244	273
28	119	59.15			195	207	266
29	136	55.46			205	222	266
30					195	207	268
31	121	58.51			195	208	259
32	176	47.22			227	256	264
33					225	252	265
34					221	247	265
35	171	48.02			224	251	267
36	171	48.02			234	266	260
37					227	256	259
38					191	201	216
39	151	51.29			215	237	245
40					233	265	269
41	176	47.3			228	257	267
42					225	253	264
43	160	49.57			218	242	259
44	172	45.3			225	253	268
45					230	260	269
46					246	285	252
47	367	26.45			279	334	286
48	198	44.55			240	276	269
49					231	262	265
50	258	37.56			282	338	260
51					283	341	270

	AA	AB	AC	AD	AE	AF	AG
52	366	29.13			285	343	271
53					276	329	254
54	255	38.1			277	332	264
55					267	316	256
56					272	323	268
57					270	320	262
58	204	44.23			244	282	270
59					246	285	272
60	224	41.5			256	299	269
61	196	45.37			241	276	266
62	189	46.2			235	269	269
63	357	29.39	236.5	39.48	252	294	276
64	359	29.45			266	314	274
65	362	28.59			252	294	280

	AH	AI	AJ	AK	AL	AM
1	Al 4 Corr	T K & M	Tcat88-all	Tcat88-LA	Tcat88-SS	10000/T:LA
2	2.2217	254	252	252	266	19.178686
3	1.08249	133	73	56	159	27.501344
4	2.01436	232	215	212	244	20.8784831
5	2.13451	244	231	229	254	20.1379076
6	2.12334	243	230	228	253	20.1802262
7	1.96335	226	209	206	241	21.1465009
8	2.33521	266	259	260	271	18.826031
9	2.48907	282	280	283	283	17.8738625
10	1.9479	224	207	203	239	21.2593505
11	1.9057	220	201	197	236	21.5203152
12	1.93487	223	204	200	238	21.4004125
13	1.98738	229	212	209	243	21.0195451
14	1.97654	228	211	207	242	21.0759699
15	2.50066	283	282	285	284	17.768066
16	2.29848	262	255	256	268	19.0235178
17	1.92733	222	205	201	238	21.3580939
18	1.99603	230	214	210	243	20.9490141
19	1.85625	215	194	189	232	21.858864
20	1.80276	209	186	180	227	22.2397314
21	1.92571	222	204	200	238	21.3863063
22	2.39578	272	268	270	276	18.4169512
23	1.9275	222	205	201	238	21.3369346
24	2.17909	249	239	238	259	19.7499871
25	2.02749	233	216	213	245	20.8432176
26	2.0937	240	224	221	249	20.4835095
27	2.25119	257	245	245	262	19.4749162
28	2.01899	232	211	207	242	21.083023
29	2.09168	240	225	222	250	20.4341378
30	2.00163	230	211	207	242	21.083023
31	2.01346	231	212	208	242	21.0407044
32	2.24443	256	257	258	269	18.9318275
33	2.21916	253	253	254	267	19.1011019
34	2.18293	249	248	248	264	19.3409073
35	2.21112	252	252	253	267	19.1504736
36	2.31089	263	267	269	275	18.473376
37	2.24395	256	257	258	270	18.9247744
38	1.9223	222	205	201	238	21.3580939
39	2.12857	244	239	238	259	19.7640933
40	2.30142	262	265	267	274	18.5509601
41	2.25066	257	258	258	270	18.9036151
42	2.22652	254	254	254	268	19.0799426
43	2.14478	245	243	243	261	19.5595534
44	2.24545	256	254	255	268	19.0587833
45	2.29087	261	261	262	272	18.7555
46	2.45946	279	284	287	286	17.6834288
47	2.77781	312	331	339	314	15.4969678
48	2.40262	273	276	278	281	18.05019
49	2.30599	262	262	264	273	18.6779159
50	2.87539	323	335	343	316	15.3206403
51	2.89577	325	337	345	318	15.2077907

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	AH	AI	AJ	AK	AL	AM
52	2.9076	326	339	348	319	15.1019942
53	2.82478	317	326	333	311	15.7156139
54	2.83315	318	328	336	312	15.6239236
55	2.73017	307	313	319	303	16.3151274
56	2.7737	312	320	327	307	15.9836317
57	2.75264	310	318	324	306	16.1105875
58	2.46879	280	282	285	284	17.7892253
59	2.48315	281	284	287	286	17.6834288
60	2.58113	292	298	302	294	17.0345436
61	2.43282	276	276	279	281	18.0360838
62	2.37085	269	269	271	277	18.3816857
63	2.53888	287	293	297	291	17.274349
64	2.68115	302	312	318	302	16.3786053
65	2.5407	287	292	297	291	17.2814021

	AN	AO	AP	AQ	AR
1	T:LA	10000/T:all	T: all	Al IV Walshe	TCN85,WAl4
2	248	19.272002	246	1.6774	196
3	90	26.466108	105		
4	206	20.7413067	209	1.367	163
5	223	20.1011532	224	1.483	175
6	222	20.1377334	223	1.4876	175
7	200	20.9729813	204	1.3442	160
8	258	18.967167	254	1.726	201
9	286	18.1441125	278	1.8934	219
10	197	21.0705285	201		
11	192	21.2961064	196	1.2776	153
12	194	21.1924625	199		
13	203	20.8632407	206		
14	201	20.9120143	205	1.3446	160
15	290	18.052662	281	1.9082	220
16	253	19.1378746	249		
17	195	21.1558823	200	1.3144	157
18	204	20.8022737	208		
19	184	21.588748	190	1.222	147
20	176	21.9179698	183	1.1676	141
21	194	21.1802691	199		
22	270	18.6135584	264	1.798	208
23	196	21.1375922	200		
24	233	19.7658347	233	1.5564	183
25	207	20.7108232	210	1.3562	162
26	215	20.3998915	217		
27	240	19.5280634	239	1.584	186
28	201	20.918111	205	1.3006	156
29	216	20.3572146	218	1.4366	170
30	201	20.918111	205		
31	202	20.8815308	206	1.3246	158
32	255	19.0586175	252	1.631	191
33	250	19.2049383	248		
34	244	19.4122261	242		
35	249	19.2476152	246	1.6878	197
36	268	18.662332	263	1.6876	197
37	255	19.0525208	252		
38	195	21.1558823	200		
39	233	19.7780281	232	1.5888	186
40	266	18.7293957	261		
41	256	19.0342307	252	1.623	190
42	251	19.1866482	248		
43	238	19.6012238	237	1.6314	191
44	252	19.1683581	249	1.6936	197
45	260	18.9062	256		
46	292	17.9795016	283		
47	372	16.0895246	348	2.3392	266
48	281	18.29653	273	1.8576	215
49	262	18.8391363	258		
50	380	15.9371071	354	2.2552	257
51	384	15.8395599	358		

CattleyChlorite Data.5

	AN	AO	AP	AQ	AR
52	389	15.7481094	362	2.4752	280
53	363	16.2785223	341		
54	367	16.1992652	344	2.2182	253
55	340	16.7967418	322		
56	352	16.5101969	333		
57	348	16.6199375	329		
58	289	18.0709521	280	1.8954	219
59	292	17.9795016	283		
60	314	17.4186052	301	2.017	232
61	281	18.2843366	274	1.8564	215
62	271	18.5830749	265	1.8024	209
63	306	17.625893	294	2.1866	250
64	337	16.8516121	320	2.3108	263
65	306	17.6319897	294	2.1614	247

TECHNIQUES: APPLICABILTY AND LIMITATIONS

1. Chlorite Geothermometry

Two types of thermometers exist:

a) Empirical thermometers
b) Thermodynamically calculated thermometers.

Empirical thermometers

The chemical formula for chlorite can be expressed as:

$[Mg, Fe^{+2}, Mn, Al]_{12} [(Si, Al, Fe^{+3})_8 O_{20}] [OH]_{16}$

where the first group of cations are octahedrally co-ordinated in the structure and the second group are tetraherally co-ordinated by oxygen.

Based on studies of active geothermal fields in the Los Azufres area, Mexico and the Salton Sea area, California Cathelineau and Nieva (1985) and Cathelineau (1988) noted an excellent correlation between the content of tetrahedrally co-ordinated aluminium of hydrothermal chlorites and temperature with a regression co-efficient of 0.97 over the temperature range 130 to 325°C. Cathelineau (1988) noted that his thermometer applied in a general way to chlorites formed at temperatures as high as 350°C at Larderello, Italy and diagenetic chlorites formed at temperatures as low as 100 to 140°C in Colorado and the North Sea.

However his geothermometer is calibrated most precisely between 200 and 300°C, and only one data point exists below 170°C. Also Cathelineau assumes that all iron is present in the divalent state. This is likely to lead to overestimation of the amount of tetrahedrally co-ordinated Al, and consequently of temperature, particularly of chlorites formed at temperatures of less than 200°C.

The results spreadsheet (Appendix 3) lists a number of the empirical thermometers:

Column AE	T CATAL	Original Cathelineau & Nieva (1985) based on the Al(IV) content of Los Azufres chlorites.
Column AF	T CATAL NEW	Cathelineau (1988) Al(IV) thermometer based on Los Azufres and Salton Sea data.
Column AG	T CATVAC	Cathelineau and Nieva (1985) calibration based on the vacany in the chlorite stucture which is inversely proportional to temperature. Only valid below 290°C where the octahedral site vacancy drops to zero.

Column AI	T K & M	Thermometer established by Kranidiotis and Maclean (1987). An attempt to correct the CATAL thermometer for variations in the Fe/Mg ratio of chlorite.
Column AJ	Tcat88-all	Based on regression by G.Green of Cathelineau's Los Azufres and Salton Sea data.
Column AK	Tcat88-LA	Based on regression by G.Green of Cathelineau's Los Azufres data.
Column AL	Tcat88-SS	Based on regression by G.Green of Cathelineau's Salton Sea data.
Column AN	T:LA	Based on regression by G.Green of Cathelineau's Los Azufres data against 1/T(°K) which is more valid thermodynamically than regression against T (°C).
Column AP	T: all	Based on regression by G.Green of Cathelineau's Los Azufres and Salton Sea data against 1/T(°K) which is more valid thermodynamically than regression against T (°C).
Column AR	TCN85, WAl4	Based on applying the CATAL thermometer to the tetrahedral Al IV content of chlorite corrected for ferric iron content by the program of Walshe (1986).

Thermodynamically calculated thermometers

Walshe (1986) developed a geothermometer based on the consideration of chlorite as a solid solution of six components, the thermodynamic properties of which were either known or could be reasonably estimated. His model specifically calculates the ferric iron and water contents of chlorite from electron microprobe analyses from the following equilibria and from a formulation of the Gibbs-Duhem equation:

$$2\ \underset{\text{component 2}}{Mg_5Al_2Si_3O_{10}(OH)_8} + 14/3\ SiO_2 + 8/3\ H_2O\ (l) \rightarrow$$

$$\underset{\text{component 5}}{Al_4Si_4O_{10}(OH)_8} + 10/6\ \underset{\text{component 1}}{Mg_6Si_4O_{10}(OH)_8}$$

and:

$$3/7\ \underset{\text{component 3}}{Fe^{+2}{}_5Al_2Si_3O_{10}(OH)_8} + 25/21\ SiO_2 \rightarrow$$

$$10/7\ \underset{\text{component 6}}{Fe^{+2}{}_4Fe^{+3}Al_2Si_3O_{11}(OH)_7} + 10/6\ \underset{\text{component 1}}{Mg_6Si_4O_{10}(OH)_8} + 8/3\ H_2O\ (l)$$

The technique involves solution of non-linear equations and is computer intensive but, apart from the estimation of thermodynamic data for the six components, the model rests on only one assumption: *co-existence in equilibrium of chlorite and quartz.* In general my experience of the chlorite model is that there is very good agreement between temperatures derived from it and other methods of temperature estimation particularly in reduced hydrothermal systems at T> 250°C and under these conditions there is also usually good agreement with the Cathelineau and Nieva (1985) Al (IV) method. Under lower temperature, more oxidised, conditions the Walshe model is preferred because it is more rigorous. Temperatures calculated by the Walshe model at liquid-vapour pressure and one kilobar are listed in Appendix 3 in columns AA and AC respectively.

Care must be exercised with both methods in metamorphic terrains particularly where chlorite has an oppportunity to re-equilibrate (i.e. exchange silica) with quartz during prograde or retrograde metamorphism. In addition reliable results are usually only achievable with hydrothermal chlorites. The rocks from the Mt Cattley-Hellyer area are unusual in the Tasmanian context in that undeformed vesicle chlorites enable these conditions to be met.

2. Fluid Inclusions

FLUID INCLUSIONS

Introduction

During processes of crystal growth, recrystallisation or fracture healing small proportions of of the fluid medium may be trapped as fluid inclusions. Fluid(s) may be trapped either during crystal growth in growth irregularities to form PRIMARY fluid inclusions or at some later time by processes of recrystallisation to form SECONDARY fluid inclusions.

PSEUDOSECONDARY fluid inclusions are those formed along the fractures during the growth of a crystal.

Most of fluid inclusions range in size from 3 to 20 µm.

Compositions of fluid inclusions vary widely. However, the major solvents are H2O and less commonly CO2 and the major solute ions include Na, K, Ca, Mg, Cl, SO4 and HCO3 with Li, B, Al, Fe, F, Mn, and Si being as minor solute ions. Major constituents in inclusions with organic liquid or gas include H2< CH4< C2H6 as well as a variety of high molecule weight compounds.

Fluid inclusions normally have a vapour or gas bubble which may move constantly under the effect of a thermal gradient or of gravity. The volume coefficients of thermal expansion for minerals are less than the water by up to 3 times. Therefore upon cooling, a fluid inclusion which has been formed form as homogeneous fluid at elevated temperatures will shrink more than host mineral, and when the total vapour pressure of the fluid is more than the pressure in the inclusion a bubble will nucleate and grow. The process can be reversed simply by heating the fluid inclusion to the temperature at which the bubble disappears(i.e. homogenisation temperature).

The salinity of fluid inclusions (wt% NaCl equivalent) can be estimated by freezing the fluid inclusions and measuring the depression of the freezing points of the inclusions. This is just an estimate, as other solute ions such as

Mg, Ca, etc. may also be present in the fluid. There are many methods (non-destructive and destructive) to determine the compositions of the fluid inclusions and these have been explained in detail by many workers (eg. Roedder, 1984). More recent microanalytical techniques the reader is referred to Geoch. et Cosmoch. Acta, v.54, 1990.
In general fluid inclusions can be utilised to define the possible environment of ore formation (eg. epithermal, mesothermal), and in studies of physicochemical conditions of ore-forming fluids. They can also be used in igneous and metamorphic terrains, in oil exploration , in active geothermal systems and in many other fields.

3. Oxygen Isotopes

Oxygen isotope compositions of minerals can be used as geothermometers in situations where co-existing minerals formed in mutual equilibrium and have not subsequently undergone isotopic exchange *or* in cases where the oxygen isotope composition of a hydrothermal fluid from which a mineral formed can be determined independently or be reasonably inferred.

In volcanogenic massive sulphide deposits numerous studies have shown that the $\delta^{18}O$ value of fluids that formed deposits ranging in age from Archaean to Tertiary is generally close to the seawater value of 0‰. Fluids precipitating calcite in chimneys and mounds in a sulphide-forming submarine geothermal system on a sedimented spreading rift, the Guaymas Basin, Gulf of California, have $\delta^{18}O$ values ranging from -0.8 to 4‰ (Peter and Shanks, 1992).

In the case of the Mount Cattley samples $\delta^{13}C$ and $\delta^{18}O$ values of hydrothermal vesicle- and vein-forming carbonates were determined by Mr R.N. Woolley. The temperatures of carbonate formation were calculated for fluid $\delta^{18}O$ values of 0, 1, 2 and 3‰ using the equation:

$$\delta^{18}O_{calcite} - \delta^{18}O_{water} = 2.78 * 10^6/T^2 - 2.89; \qquad \text{where T is in °K.}$$

For each of these cases the $\delta^{13}C$ value of the H_2CO_3 in the fluid was calculated from the equation:

$$\delta^{13}C_{H2CO3} = \delta^{13}C_{calcite} + 8.914 * 10^8/T^3 - 8.557 * 10^6/T^2 + 18110/T - 8.27$$

In submarine basaltic hydrothermal systems the fluid $\delta^{13}C$ value is generally close to 0‰ (Muehlenbachs, 1986). In the Guaymas Basin calcite $\delta^{13}C$ values are much lower consistent with deposition from a fluid with a value of about -11‰, reflecting roughly equal carbon inputs from seawater (0‰) and oxidised organic matter from the sediments (-21‰) (Peter and Shanks, 1992). An additional contribution from magmatic CO_2 (-7‰) cannot be ruled out either from these data. Carbonates from Tasmanian VMS deposits appear to have carbon derived from a mixed seawater- magmatic source ($\delta^{13}C$ = -5 to +0.6‰; Khin Zaw and Large, 1990).

Appendix 5. Depth-temperature data.

Depth-Temp.Mt.Cat.

Hole No.	Depth wrt OH	Technique	T, °C
MXRD1	139	chlorite	169
	-5		126
	-5		140
	-5		141
	-22.4		122
	-22.4		166
	-22.4		190
	-22.4		115
	-22.4		122
	-22.4		194
	-22.4		119
	-22.4		108
	-22.4		101
	-22.4		177
MCPD6	167.3		151
	167.3		125
	167.3		158
	167.3		119
	167.3		136
	23.9		121
	23.9		176
	23.9		171
	23.9		171
	23.9		151
	23.9		176
	23.9		160
	0		172
	0		367
	0		198
	0		258
	-30		366
	-30		255
	-90		204
	-90		224
	-90		196
	-90		189
	-90		357
	-90		362
MXRD1	124.3	O18, Fluid=2	89
	103.6		120
	50.9		57
	-5.5		124
	-29.8		125
	-51.5		134
MCPD6	226		132
	143		145
	135		153
	125		122
	124		130

	86		173
	44		139
MXRD1	-30	Fluid incl.	116
	-30		115
	-30		121
	-30		126
	-30		132
	-30		126
	-30		129
	-30		138
	-30		123
	-30		118
	-30		122
	-30		141
	-30		121
	-30		118
	-30		121
	-30		121
	-30		117
	-30		124
	-30		119