Hydrothermal fluid chemistry in exploration. Acoustic decrepitation as a method of locating potentially auriferous quartz systems formed from CO_2 rich fluids.

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SUMMARY

There is a well documented relationship between Au mineralized quartz and CO_2 rich fluid inclusions within that quartz, indicating the CO_2 rich nature of the parent hydrothermal fluids. This relationship has been suggested to be a function of CO_2 buffering the Ph of the geothermal fluids in a range which enhances gold solubility. It is also known that the acoustic decrepitation method can identify quartz formed from fluids which had high CO_2 contents, as CO_2 rich fluid inclusions decrepitate upon heating at temperatures well below that of aqueous inclusions trapped under the same pressure and temperature conditions. CO_2 contents at least as low as 5 mole % are readily detectable using the acoustic decrepitation method.

The decrepitation method has been applied to a number of gold deposits in Victoria and shows that CO_2 is a common but not ubiquitous constituent of the fluid systems which deposited the quartz and gold. Although the precise relationship between CO_2 and gold is not clear, the method provides a means to 'fingerprint" quartz veins as an exploration guide. Samples from the Meguma terrane in Nova Scotia also show widespread but variable levels of CO_2 rich fluids in the gold deposits.

Knowledge of the CO_2 contents of quartz systems is a valuable exploration tool and the acoustic decrepitation method is the easiest way to acquire this information for exploration purposes as it is an automated and quick instrumental procedure.

Key words: fluid inclusions, gold, carbon dioxide, decrepitation.

INTRODUCTION

The relationship between gold mineralised quartz and formational fluids which were rich in CO_2 is well documented but has not been effectively used in exploration for gold because of the difficulty of measuring CO_2 contents in fluid inclusions using the traditional microthermometric methods. Some authors have also stressed the importance of methane and nitrogen over carbon dioxide and inferred that it is necessary to use expensive laser raman analyses to obtain useful gas analyses from fluid inclusions. However, the acoustic decrepitation method readily determines the total contents of these gases in fluid inclusions without the need for tedious microscope work or complicated sample preparation. High contents of these gases in fluid inclusions gives a distinctly recognizable low temperature decrepitation response between 200 C and 300 C. This decrepitation behavior is due to the CO_2 (and other non-condensing gases) expanding upon heating in approximate accordance with the gas law, $PV=nRT$, whereas aqueous inclusions undergo condensation to a liquid phase and do not generate significant internal pressure upon heating until after the liquid and vapour phases homogenize. Consequently the CO_2 rich inclusions develop high internal pressures sufficient to burst the host mineral grain at much lower temperatures than the aqueous inclusions. (Figure 1) The gas law applies to all species of gases and so the presence of methane or nitrogen does not reduce this effect unless there is some other fundamental difference in the trapping or preservation conditions of the inclusions.

Decrepitation analyses from deposits in the Victorian goldfields show that CO_2 is a common but variable constituent in the auriferous quartz and may thus be used to distinguish between different generations of quartz formed from different hydrothermal fluids of potentially different Au potential (i.e. to "fingerprint" potentially auriferous quartz). Although the levels of CO_2 in fluid inclusions from the Victorian deposits are quite modest (in contrast to the very high CO_2 contents in quartz from the Archaean metamorphogenic deposits in Western Australia), samples with noticeable CO_2 levels often correlate with known mineralization, as at the Central Deborah mine in Bendigo. In other locations, such as at Ballarat, the CO_2 rich quartz does not correlate well with the Au analyses, but this quartz is quite inhomogeneous on a scale of centimetres, indicating considerable variation in the parental fluids during deposition.

Samples from the Meguma terrane in Nova Scotia have been compared with those from Victoria and many but not all of the Nova Scotia deposits are also associated with CO_2 rich fluids.

METHODS

The acoustic decrepitation method avoids the requirement for microscopy or preparation of polished thin sections and uses about 1 gram of crushed and screened monomineralic material, usually quartz, so the sample preparation is simple. The instrument used in this work was the BGS model 105 decrepitometer. The sample is heated at 20 C per minute from 100 C to as much as 800 C and as fluid inclusions generate high internal pressures they burst and are detected with a pressure sensitive detector. These bursts are counted in the computer and plotted as a histogram of inclusion bursts (counts) within each 10 C temperature rise interval (Y axis) against temperature on the X axis. An explanation of typical decrepigrams is shown in Figure 2.

RESULTS

Victoria

Samples were collected from a number of gold deposits in Victoria, including Fosterville, Bendigo, Wattle Gully and Ballarat. In the Victorian goldfields samples commonly show modest levels of CO_2 in their fluid inclusions. However the presence of CO_2 is not perfectly correlated with known Au mineralisation, indicating that the quartz growth was quite complex from fluids of different compositions even on a scale of centimetres. Several results from these Victorian mines are shown in Figure 3. At Fosterville, about half of the samples collected contained significant amounts of CO_2.

Many samples were collected from the various anticlines at Bendigo. All of the anticlines had occasional samples containing CO_2 and it was not possible to distinguish between the different anticlinal zones based solely on the decrepitation data.

A number of samples were collected at the Central Deborah tourist mine, and the main mineralised saddle reef in this mine contained a significant amount of CO_2 (green histogram) while a nearby sample from a barren quartz reef (blue histogram) lacked any CO_2.

Gold mineralised samples from Wattle gully and from a borehole at Ballarat also contained high levels of CO_2.

However, the relationship between gold and CO_2 is irregular and many cases of CO_2 in supposedly barren quartz were also obtained. This data highlights the complexity of the quartz and mineralisation processes, both of which have occurred over a long time period from fluids of changing composition, despite the lack of visibly discernible variations in the quartz lodes.

Nova Scotia, Canada

Samples were collected from numerous old gold mines in eastern Nova Scotia, hosted by sediments of the Meguma terrane. Although CO_2 rich fluid inclusions occurred in a number of samples, they were not quite as commonly found as in the Victorian samples. A selection of results is shown in Figure 4.

At the Dufferin mine, samples from mine ore dumps had both high and low CO_2 contents showing again that the quartz is far from homogeneous even within a single ore zone.

At the Skunk's den mine, where vein sets of different orientations could be sampled, there was no consistent decrepitation difference between veins of different orientations. The often used technique of using vein orientation to discriminate between mineralisation events is clearly not a reliable indicator of different fluids and should not be relied upon as a mineralisation guide without careful fluid inclusion study to validate the assumption that different fluid events are correlated with different stress regimes.

CONCLUSIONS

Acoustic decrepitation is a sensitive and quick method to obtain fluid CO_2 compositional information from fluid inclusions which represent the original ore forming fluids. This information is very useful in exploration for Au bearing quartz and is an important step in making use of fluid inclusion data to assist in exploration, rather than merely consigning fluid inclusion studies to post-discovery genetic research.

The fluid inclusion data shows that quartz lode formation is usually a complex process from fluids of varying compositions over time and distances of centimetres. These growth stages in the formation of the quartz, and Au mineralisation, are not generally visible in hand specimen, but need to be carefully considered in exploration programmes.

Fluid inclusion information is one of the few ways to understand quartz lode and mineralisation deposition thoroughly, and acoustic decrepitation data is the easiest way to obtain representative gas content data from fluid inclusions.

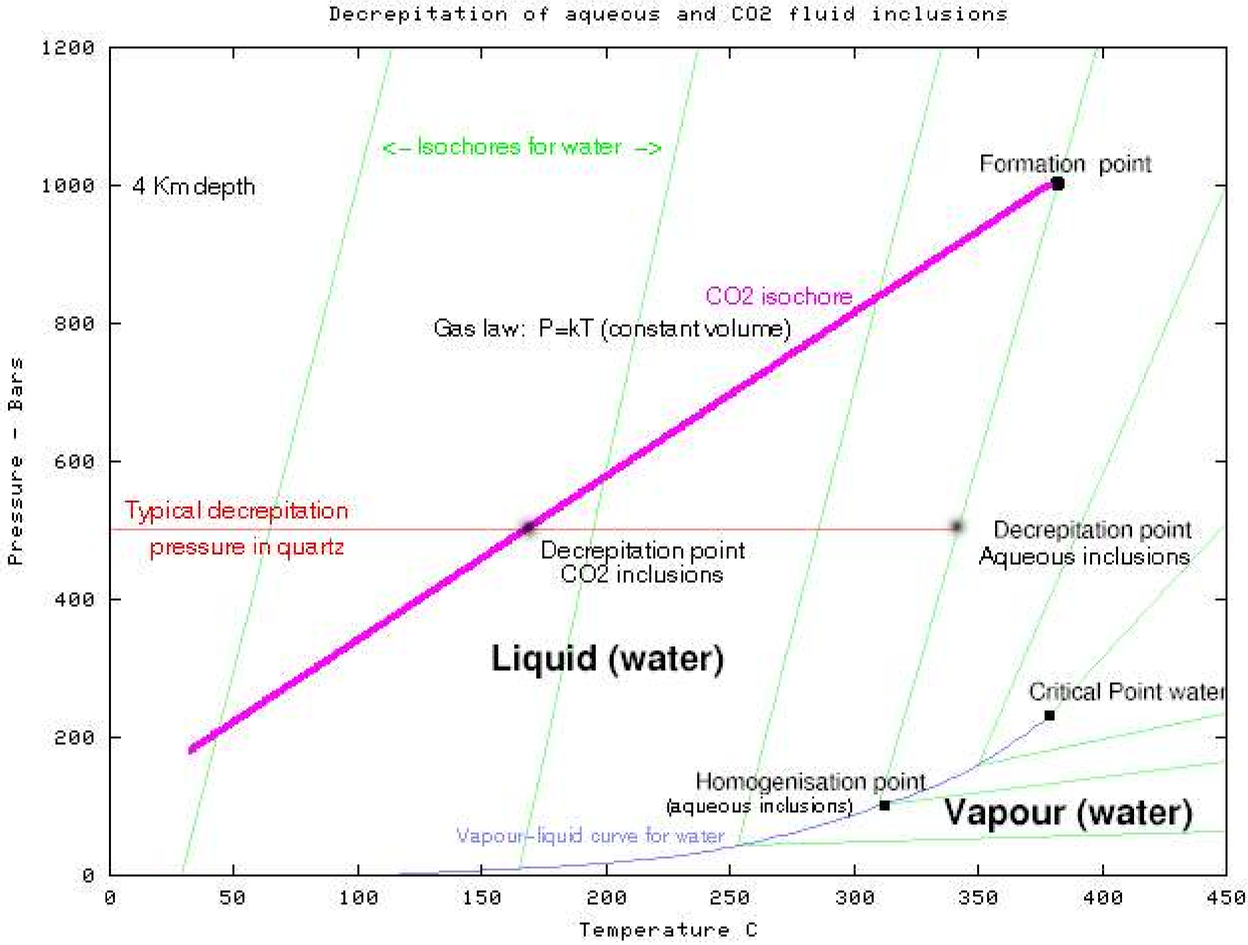

Figure 1

When heated, pure gas inclusions will follow a path close to the CO_2 isochore (magenta) line and quickly develop enough internal pressure to decrepitate at low temperatures. However aqueous inclusions which homogenise to a liquid phase, will follow a path along the vapour-liquid curve for water (blue) until they homogenise at the homogenisation point, and then along the water isochore (green) and will not develop a high internal pressure until above the homogenisation temperature. These aqueous inclusions will decrepitate at temperatures close to their formation temperature. Inclusions containing mixed water and gases will follow paths between these two extremes. All gases follow approximately the same P-T relationship because they behave in accordance with the gas law and so other commonly observed gases in fluid inclusions, such as CH_4 and N_2, will result in the same decrepitation behaviour as CO_2.

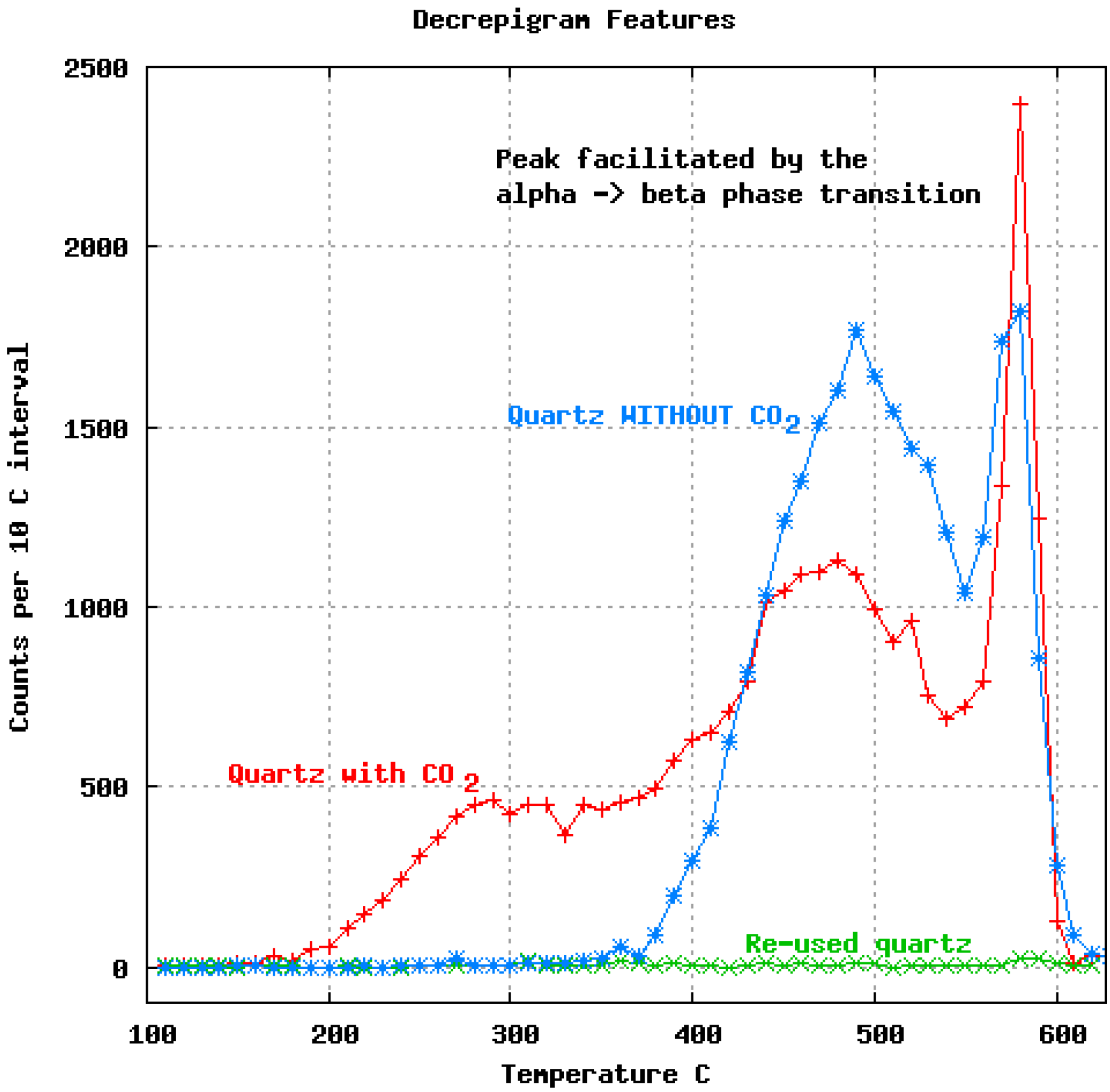

Figure 2

Typical decrepitation results for quartz. Plain quartz lacking gas rich inclusions is plotted in blue, with primary inclusions causing the peak near 500 C. The temperature of this peak varies according to the formation temperature of the quartz. Note that there is no low temperature decrepitation which might be expected to be caused by low-temperature secondary inclusions, as such inclusions do not generate sufficiently large pressure pulses to be detected. On the red decrepigram, the low temperature decrepitation peak is caused by the presence of CO_2 rich fluid inclusions which decrepitate at low temperatures because they generate very high internal pressures in accordance with the gas law. This peak is diagnostic of all inclusions containing non-condensable gases, including CH_4 and N_2 as well as CO_2. The green decrepigram is of quartz which has been previously analysed and now shows no response at all because all the fluid inclusions decrepitated during the first analysis. This confirms that all the counts measured are caused by the irreversible decrepitation of fluid inclusions, rather than crystallographic, mechanical or thermal expansion events, as such events are reversible and would re-occur on a subsequent analysis of the same sample.

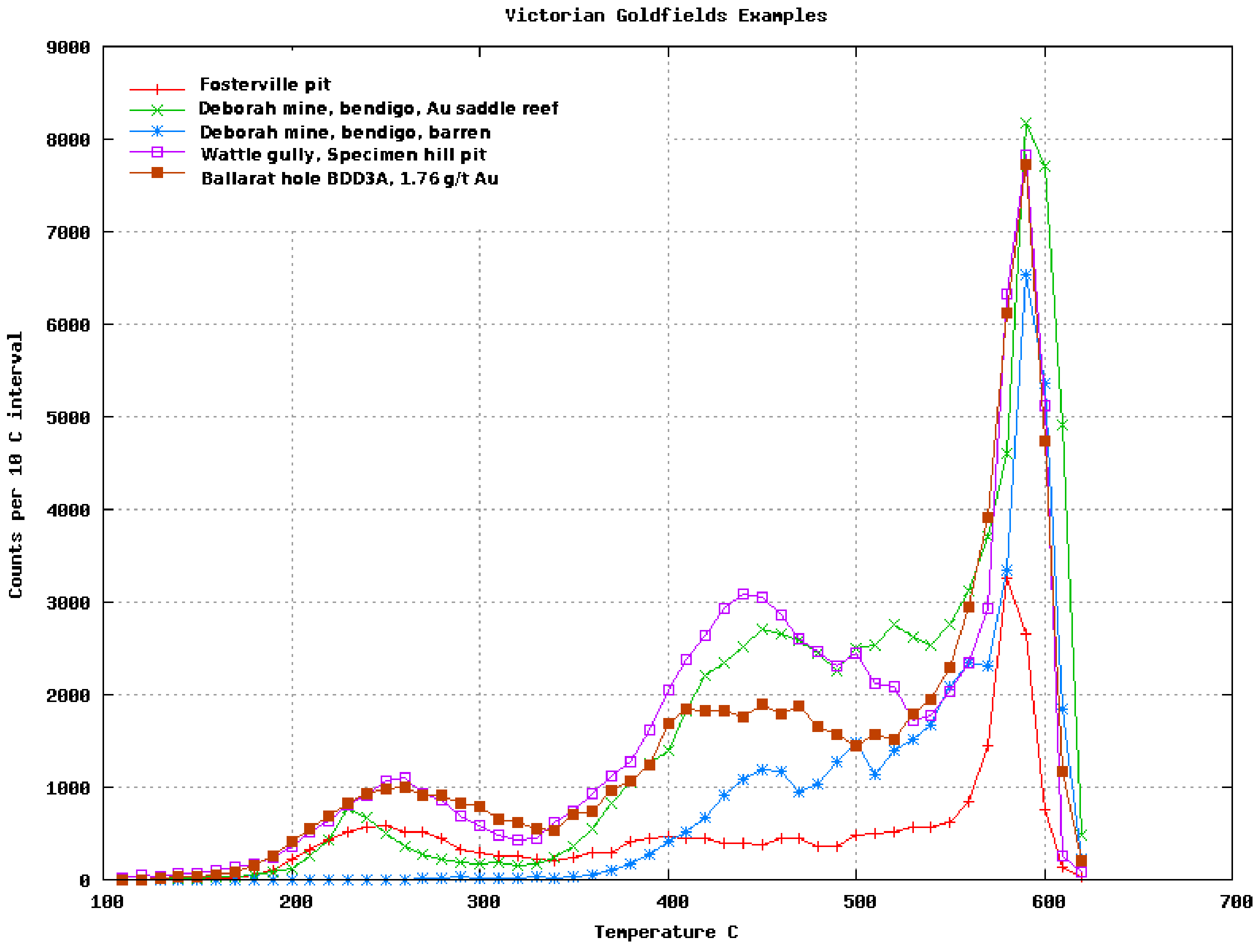

Figure 3

Representative results from Victorian Au deposits. CO_2 rich fluid inclusions are quite common in Victorian gold deposits, but there is not always a 1:1 correlation between the high CO_2 contents and Au mineralisation. This is because quartz formation is almost invariably a complex multi-stage event from many fluid compositions over long time periods. In addition, the CO_2 rich fluids in inclusions are expected to be more widespread than the Au deposition locations and thus be useful as a large target aureole around the actual mineralisation.

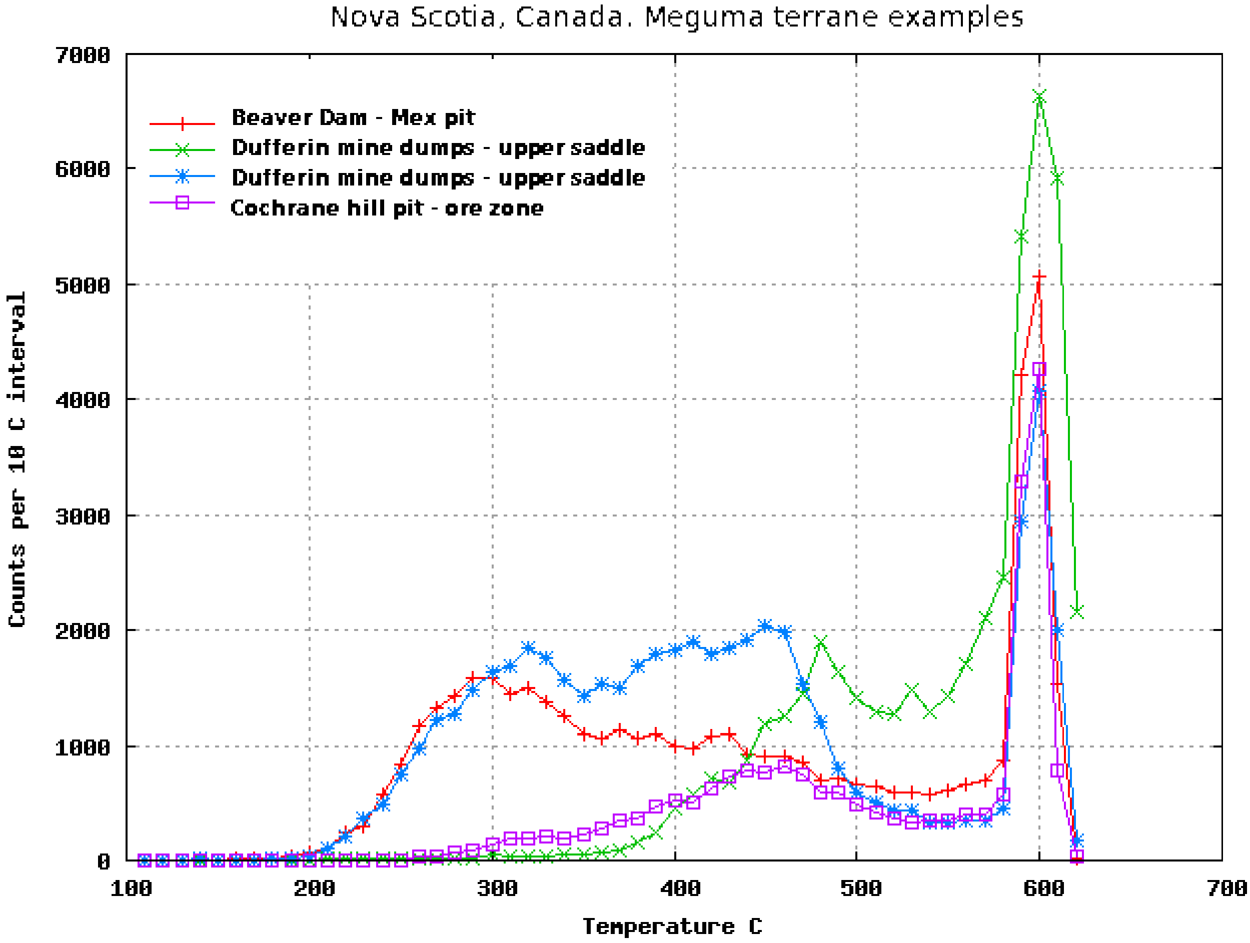

Figure 4

Representative results from the Meguma terrane Au deposits, Nova Scotia, Canada. CO_2 rich quartz occurs throughout the deposits in this region, although possibly less frequently that in the Victorian deposits. The 2 samples from the Dufferin mine dumps (the underground workings were not accessible) have very different CO_2 contents despite being from the same "upper saddle" ore zone. At the abandoned Cochrane hill pit, samples from the (presumed) ore zone lacked CO_2, but several samples from other sections of the pit did have significant CO_2 contents. None of the mines in Nova Scotia were operational in 2002 when the samples were collected.