

An instrument for fluid inclusion decrepitation and examples of its application

by KINGSLEY BURLINSON

Burlinson Geochemical Services Pty. Ltd., P.O. Box 37134, Winnellie 5789, N.T., Australia.

Abstract. — A decrepitation instrument has been constructed which provides rapid, reliable and fully automated analyses and it has been used to analyse some 3 000 samples to evaluate the application of decrepitation data in mineral exploration.

Monomineralic samples of 0.5 g of crushed, sieved grains are analysed and extensive studies have been done using magnetite, pyrite, galena, carbonates and quartz. Quartz vein samples often show three or more distinct decrepitation peaks. A peak at 570 °C is related to the weakening of quartz during the alpha to beta phase transition, which facilitates the decrepitation of inclusions. A low temperature peak (below 300 °C) is due to the presence of gas-rich inclusions (the most common gas being CO₂), while the intermediate temperature peak is due to primary inclusions. Pyrite and quartz of hydrothermal origin usually give strong decrepitation responses whereas sedimentary pyrite or low temperature cherts give negligible decrepitation. Carbonate samples give very intense decrepitation up to their thermal decomposition temperatures, at which point the decrepitation suddenly ceases.

Because of the speed and low cost of the analyses, the technique is useful for exploration projects and for scanning and selecting samples prior to conventional microthermometric studies.

Key-words: fluid inclusions, decrepitation, instrument, exploration.

Un enregistreur décrépitométrique pour les inclusions fluides et son application.

Résumé. — Un instrument de décrépitation a été construit qui fournit des analyses rapides, sûres et complètement automatisées. Il a été employé pour analyser quelque 3 000 échantillons afin d'évaluer l'application de cette méthode à la prospection minière.

Les échantillons monominéraux de 0.5 g de grains broyés et criblés sont analysés ; des études ont été faites employant magnétite, pyrite, galène, carbonates et quartz. Les échantillons des filons de quartz montrent souvent au moins trois pics distincts de décrépitation. Un pic à 570 °C est lié à l'adoucissement du quartz lors de la transition de phase α - β , qui favorise la décrépitation des inclusions. Un pic à une température inférieure à 300 °C est causé par la présence d'inclusions riches en gaz (le plus commun étant CO₂) et le pic de température intermédiaire est causé par les inclusions primaires. Pyrite et quartz d'origine hydrothermale donnent normalement des réponses de décrépitation fortes, alors que la pyrite sédimentaire ou le chert de basse température donnent une décrépitation négligeable. Les échantillons de carbonate donnent une décrépitation très intense jusqu'à leur température de décomposition thermique, à laquelle la décrépitation cesse soudainement.

Par sa vitesse et son faible coût, la technique est utile pour les projets de prospection et pour la sélection des échantillons en vue d'études microthermométriques conventionnelles.

Mots-clés: inclusions fluides, décrépitation, instrument, prospection minière.

I. INTRODUCTION

The decrepitation method of fluid inclusion analysis was first introduced by Scott (1948) but fell into disfavour in the early fifties. The technique was used extensively in Russia in the seventies and several decrepitation instruments were designed (Kostyleva, 1968 ; Groshenko, 1973). Since 1950 outside Russia there have been only a few attempts to re-examine the method (Pulou and Baudracco-Gritti, 1978 ;

Shan Lin and Zhang Wenzhi, 1979) although, because of the vast improvements in our understanding of fluid inclusions and in electronics since 1950, a re-evaluation of the technique is warranted. Consequently a program of instrument development and decrepitation research was begun in 1979 which has resulted in the commercial availability of the BGS model 04 instrument described herein, as well as the analysis of over 3 000 samples to develop an understanding of decrepitation in numerous minerals and geological environments.

In the decrepitation method the sample is heated until the pressure in the fluid inclusions exceeds the strength of the host mineral, at which point failure occurs. If brittle (rather than ductile) failure occurs, the pressure release can be detected by a microphone. A decrepigram is a histogram of the number of impulses due to these brittle failure events plotted versus the temperature at which they occur. The temperature at which an inclusion decrepitates (T_d) depends not only upon its formation temperature, but also on several other parameters and because of this complexity, the technique is not as accurate as microthermometry and has generally been avoided as a research method.

Factors which influence the decrepitation temperature of inclusions are: 1) The strength of the host mineral; 2) The method of failure, brittle or ductile; 3) The size of the inclusion; 4) The shape of the inclusion and 5) The composition and density of the inclusion fluids. In the simple case of a 2 phase liquid-vapour inclusion which homogenises to the liquid phase, heating above the homogenisation temperature causes the pressure to rise rapidly until the host mineral eventually fails. For a given mineral, the amount of overheating beyond T_h before decrepitation occurs depends on the inclusion size and on the composition and density of the inclusion fluid, which control the slope of the isochore (Leroy, 1979; Hladky and Wilkins, 1987a and b). However, by working with suites of similar samples, many of these factors are more or less constant and it is then possible to quickly obtain semi-quantitative decrepitation data and perform empirical interpretations of value in exploration work.

II. THE INSTRUMENT

The decrepitemeter comprises an electrically heated furnace within an acoustic isolation enclosure, an electronics unit, a video monitor, a keyboard and a printer. The electronics unit incorporates a microprocessor which controls the furnace temperature as well as collecting, organizing, displaying and printing out the data.

To commence an analysis the user sets the instrument conditions from the keyboard in response to prompts on the screen. These conditions are the starting temperature, ending temperature, amplifier threshold level, heating rate, which of the two possible furnaces to use and the number of printout copies

required. A text description of the sample for identification purposes can also be entered. After entry of this data the analysis is started and completed without further operator intervention, ensuring that the results are completely objective and free of any operator introduced bias.

The sample is placed in a fused silica tube in the furnace and the microphone is attached to the sample tube. As the decrepitation sounds are of very low level the entire furnace is mounted inside an acoustic isolation chamber to reduce interference from outside noises. Sounds exceeding the threshold level are counted by the microprocessor and displayed as a histogram on the screen.

The temperature is sensed by a platinum resistance probe in intimate contact with the sample and displayed on the screen, as well as being used to automatically control the power supplied to the furnace so that the heating rate is constant. This procedure allows for the thermal inertia of the furnace and sample so that the heating rate is independent of small changes in the thermal mass of the sample. When the temperature reaches the end temperature specified by the user the furnace power is turned off and the result is printed. The printout includes the instrument settings used, the sample title, a table of all the count values recorded in each 10 °C temperature interval and a histogram of the counts data per 10 °C interval versus temperature. This is printed as many times as was specified by the operator and can be further reprinted if additional copies are required.

After an analysis the furnace must cool down to near ambient temperature before it can be reused and this takes about half an hour. In order that analyses may be done continuously, the decrepitemeter supports the use of two furnaces so that while one is cooling, the second can be used for another analysis.

To compensate for slight changes in the temperature readings as the temperature sensors age, a temperature correction facility is included. The correction amount is determined from a calibration sample analysed at the beginning of each batch of samples and individual corrections are provided for each of the two furnaces. An audible output is provided so that the operator can hear the decrepitations and connections are provided so that the decrepitation signal and the pulses can be observed on a normal cathode ray oscilloscope if required. An RS232 communications port is provided and is used for transmission of the analytical data to an external computer. Although the instrument operates without the need for manual intervention, several controls allow the operator to intervene if necessary. These controls are normally used only for testing purposes. A facility is included such that upon completion of an analysis the decrepitemeter will turn itself off and its associated equipment (printer and monitor) off.

The acoustic isolation chamber in which the furnace is mounted provides sufficient attenuation of outside noises that the instrument can be operated in a normal laboratory. It is possible to speak beside the instrument while it is operating without causing interference, but loud speech or loud noises will interfere.

In operation the sample throughput depends upon the temperature limits and heating rates used. The most common heating rate used is 20 °C per minute as this is a reasonable compromise between analytical speed and accuracy of the data. Using this rate for analyses of quartz from 100 to 620 °C allows the analysis of one sample per half hour and with two furnaces, 15 samples per day can easily be analysed. Analyses to higher temperatures (the maximum being 800 °C) naturally take longer and reduce the production rate.

III. THE SAMPLE

The analytical sample is prepared as crushed grains which are sieved to be within a specified range of grain sizes. This simple sample preparation is a major advantage of the method. In fine grain size fractions, many inclusions are mechanically broken during the sample preparation, whereas in coarse grain size fractions the average distance from an inclusion to a grain surface is greater, which decreases the likelihood of decrepitation. Hladky and Wilkins (1987a) show the effects of variations in sample grain size upon the decrepigrams and this is in agreement with past experience that the 200 to 420 μm grain size fraction is most satisfactory for routine analyses.

The amount of sample required is only 0.5 g. If being done in conjunction with microthermometry this small amount can often be obtained from the offcuts of making the thin section. Because fluid inclusions are abundant in most samples, this small sample size does not lead to sampling error problems, as shown by the close agreement of repeat analyses of the same prepared sample (Figure 1).

A major advantage of decrepitation is the ability to use opaque samples or samples of poor optical quality. Inclusion information can thus be obtained directly on the most significant mineral phase rather than having to work on transparent minerals whose paragenetic relationship with the significant mineral phase may not be clear.

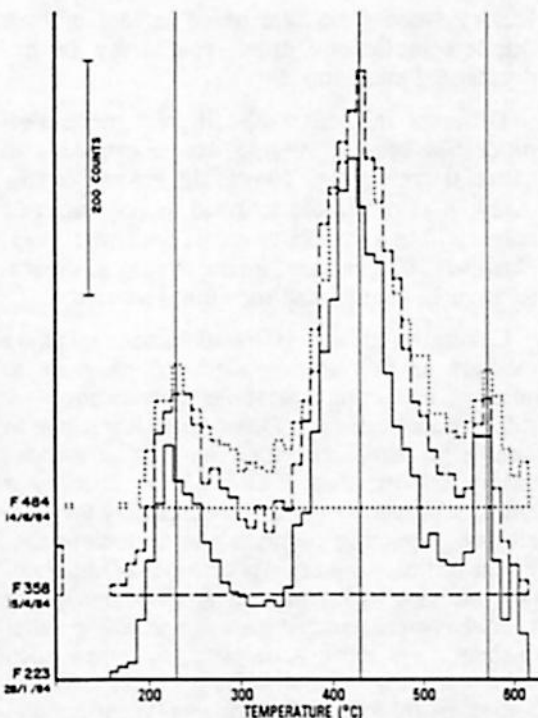


FIG. 1. — *Decrepigram reproducibility.* Three analyses of the same quartz sample over a 5 month period.

Trois analyses du même échantillon de quartz réalisées sur une période de cinq mois.

Many minerals are suitable and the following have been tested successfully to date: arsenopyrite, barite, calcite, cassiterite, chromite, dolomite, feldspars, fluorite, galena, garnet, haematite, magnetite, olivine, pyrite, pyrrhotite, quartz, scheelite and sphalerite. Unsuitable minerals include chlorite, muscovite, sericite (and presumably all layer silicates) and kaolin. Note that the hydrous minerals do not produce decrepitation counts due to dehydroxylation. Ideally the mineral sampled should have a high value of Young's modulus so that brittle rather than ductile failure occurs. On this criterion, pyrite is one of the better minerals, while quartz is less preferred as it is slightly more ductile. Galena and carbonates, due to their ductility, are not favoured although they do decrepitate. In addition, the mineral host should be capable of retaining inclusions and should be resistant to weathering. The layer silicates (e.g. chlorite) have not been found to be useful as they do not retain inclusions while feldspars, although satis-

factory when fresh, are prone to loss of their trapped inclusions upon weathering or hydrothermal alteration.

Different minerals with different mechanical properties require varying excess pressures to cause decrepitation. Hence, to ensure consistency, it is preferable to avoid mixing minerals either within a sample or across a single survey. However, if necessary, mixtures such as quartz-feldspar in granites can sometimes be used.

Generally, quartz is the preferred sampling medium as thin section work can be done to confirm and complement the decrepitation results where necessary. Quartz is also resistant to weathering and can retain its fluid inclusions despite lateritization. It also has low ductility at ambient pressure, which is theoretically favourable for generating counts in the decrepitemeter. Either ordinary vein quartz or zones of silicification of host rocks may be used. Many quartz veins have pronounced growth zonation parallel to their walls and it is necessary to sample such veins carefully. Samples from several positions across the thickness of a vein can be collected to check for the existence of growth zoning.

The carbonate minerals all decrepitate violently (well below their thermal decomposition temperatures) and almost always give exceedingly high count rates (they can overload the decrepitemeter counter circuits). It is quite possible for contaminant amounts (say 5%) of carbonate in a quartz sample to completely swamp the quartz result. If this happens, the decrepigram cannot be interpreted (the presence of carbonate is immediately obvious). Unless a deliberate study on carbonates is being done it is therefore preferable to remove them from the sample and this can usually be done by washing in acid.

Sulphide minerals can be used in their own right but they are more commonly present as contaminants in other mineral phases, in which cases they can give rise to strange peaks on the decrepigrams. Generally these do not swamp out the result from the dominant phase, but they can make the interpretation more difficult. Some sulphides oxidise within the heating range of the instrument and this generates many decrepigram counts. Such oxidation is exothermic and self sustaining and the resulting decrepigram peaks are of little interpretative use. Unless a delibe-

rate study on sulphides is being done it is best to try and exclude them from the sample, although their effect is nowhere near as bad as carbonates and trace amounts can be tolerated.

IV. INTERPRETING THE RESULTS

To check the reproducibility of the decrepitation results a standard sample of quartz has been analysed regularly over the last 2 years and there are now some 200 analyses of this sample. These results show that the long term decrepigram reproducibility is ± 1 histogram interval (10°C) and $\pm 10\%$ in amplitude of the peaks. In figure 1, three representative results of this standard analysed over a five month period are shown.

To estimate the homogenization temperature from the decrepitation data, Smith (1950) used the temperature of onset of massive decrepitation. Although this method has been used successfully in recent work (Kwak and Plummer, 1984, personal communication), Hladky and Wilkins (1987a) suggest that the temperature at the maximum of the decrepitation curve should be used instead, with a correction factor applied. They show that for most non- CO_2 -rich inclusion fluids in quartz a correction of $-75 \pm 20^\circ\text{C}$ applied to the temperature at the maximum of the decrepitation curve provides a reasonable estimate of T_h .

In microthermometric studies which have measured both secondary and primary inclusion temperatures and compared the results with decrepigrams of the same samples, no response attributable to the secondary inclusions was observed. These studies, together with the general lack of low temperature peaks in the many samples analysed to date, indicate that interference from the decrepitation of low temperature secondary inclusions is not a significant problem in practice.

Quartz samples give rise to decrepitation peaks in three distinct temperature ranges, although not all quartz gives rise to peaks in each range.

A low temperature peak beginning at 200°C or less with a maximum at $200\text{--}300^\circ\text{C}$ has been found, in all the samples studied to date, to be caused by the presence of CO_2 -rich fluids in the

inclusions. However, no detailed gas analyses have been done and gasses other than CO_2 would also contribute to this effect. The gasses give rise to rapidly rising pressures in the inclusions, resulting in decrepitation at relatively low temperatures, often below the temperature of homogenization. Shifts in the temperature of this peak are thought to relate to variations in the partial pressure of gasses in the inclusions.

A medium temperature peak (beginning at 300-400 °C, maximum 350-550 °C) is a very common feature of quartz samples. This peak can often be related to T_h of primary inclusions in the sample and is inferred to be due to decrepitation of primary inclusions.

A high temperature peak (beginning at about 550 °C, peak 570-580 °C) is commonly, but not always present. This peak is indirectly related to the alpha-beta phase transition of quartz which occurs at 573 °C, at which temperature the Young's modulus of quartz reduces, facilitating the decrepitation of inclusions which would otherwise be too small to decrepitate (Wilkins, Hladky and Ewald, in prep.).

The interpretation of decrepitation in other minerals, particularly opaques, is poorly understood due to the lack of microthermometric information on inclusions in those minerals. When using minerals other than quartz we presently rely on an empirical interpretation of a carefully selected suite of samples and estimation of homogenization temperatures is not generally possible.

A decrepitation analysis is a good statistical representation of the inclusions in a sample as most decrepitation analyses record some 3 000 to 200 000 events over the range from 100 to 600 °C. This overcomes the frequent problem in microthermometry where it is difficult to amass a statistically meaningful number of measurements on a sample and measurements made on a few inappropriate inclusions can mislead an investigation.

V. APPLICATION EXAMPLES

1 - Quartz

The great majority of the samples analysed to date have been quartz and many studies have



FIG. 2. — Location map.
Carte de localisation.

been done comparing the decrepitation and microthermometric data on the same samples. In the Pine Creek area, N.T., Australia (Figure 2), a major study of quartz veins within the Proterozoic gold province has been undertaken. This has shown that the gold mineralisation is almost invariably associated with CO_2 -rich fluids, and decrepitation results of the mineralised samples have characteristic low temperature peaks (Burlinson, 1984).

The Enterprise gold mine at Pine Creek, described by Dann and Delaney (1984), is a tightly folded anticline of hornfelsed siltstones and greywackes, throughout which are numerous quartz veins. Almost all of the gold is within the quartz and typical decrepigrams from these quartz veins are CO_2 -rich with prominent low temperature decrepitation peaks (Figure 3). Microscope observations of the decrepitation samples have confirmed the relationship between visible liquid CO_2 phases in inclusions and the presence of the low temperature decrepitation peaks. It is of interest that a prior microthermometric study at this mine failed to recognise the widespread occurrence of CO_2 , perhaps due to selection of only clear quartz samples. The ability, using decrepitation, to rapidly analyse a large number of samples and to use samples which were too cloudy for normal microscopic investigation was fundamental in discerning this relationship.

Exploration of nearby areas has focused on the search for CO_2 -rich fluids in quartz veins

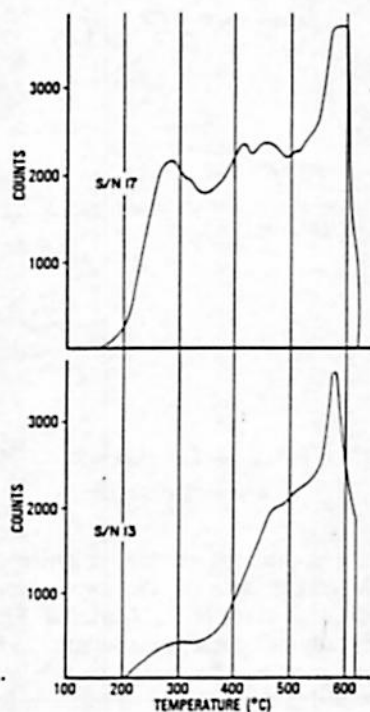


FIG. 3. — Low temperature decrepitation below 300 °C due to CO₂-rich inclusions in two quartz samples from the Enterprise gold mine, N.T.

Décrépitation à une température inférieure à 300 °C causée par des inclusions riches en CO₂ dans deux échantillons de quartz de la mine d'or Enterprise, N.T.

and in this work it has been noticed that quartz fragments a few centimetres apart in the same sample can give quite different decrepigrams. In the upper graph of figure 4, there is a substantial tail of decrepitation near 300 °C, due to the presence of CO₂-rich inclusions, whereas no such tail is seen in the lower graph from a sample just 10 cm away. This variation is due to growth banding, many of these veins having vug filled central cavities lined with euhedral quartz crystals.

In another study in the Kalgoorlie area, W.A., Australia, microthermometric work was done on the optically clear euhedral quartz crystals from the centre of a vein and this data used to deduce the conditions of formation for the entire vein, the walls of which were too milky for microscope work. The decrepitation results from samples of the vein centre and vein margin

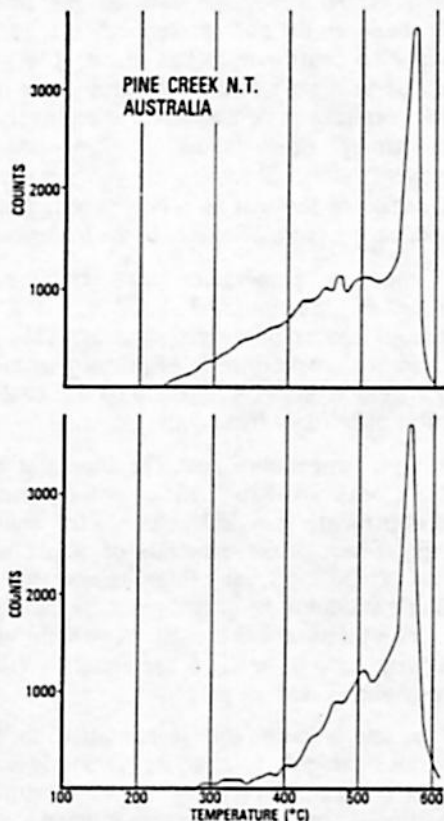


FIG. 4. — Variability of decrepitation between quartz samples 10 cm apart at Pine Creek, N.T.

Différence de décrépitation entre deux échantillons de quartz pris à 10 cm l'un de l'autre à Pine Creek, N.T.

materials just 5 cm apart show substantial differences indicating the presence of growth banding (Figure 5). In the microthermometric study the assumption was made that there was no banding in this quartz, but the decrepitation data indicates that this assumption may have been unwise.

Not all quartz show such marked variations. A study at Cracow, Qld, Australia, involving 90 samples collected over some 10 km of strike extent, resulted in decrepigrams which were little different over the entire region. Figure 6 shows two representative samples collected over 1 km apart, between which there is no significant difference. Additional sample sections taken across the veins at this mine also failed to find any evidence for growth banding. This de-

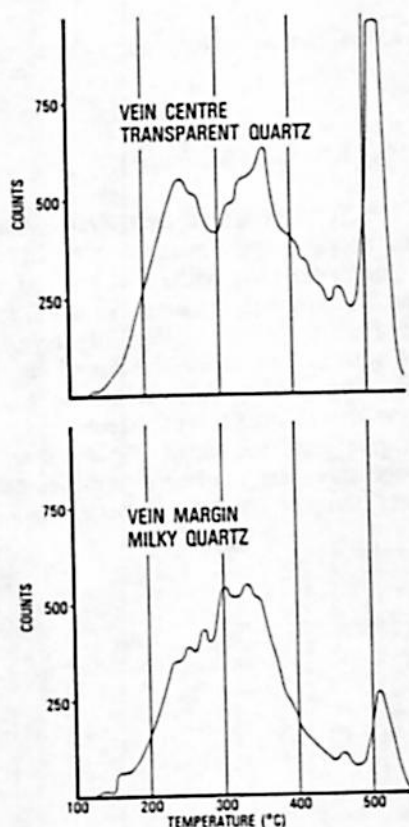


FIG. 5. — Variability of decrepitation between the vein centre and margin in a 10 cm thick quartz vein, Kalgoorlie area, W.A.

Décrépitation au centre et au mur dans un filon de quartz d'une épaisseur de 10 cm, Kalgoorlie, W.A.

posit seems to have formed at considerable depth, under conditions such that the quartz veins did not develop growth banding.

Growth zoning in quartz is quite common and the decrepitation data provides a quick test for such zonation as an aid in the selection of samples for subsequent microthermometric studies.

The occurrence of CO₂-rich fluid inclusions associated with gold mineralisation is well known and has been documented from many areas (e.g. Burlinson, 1984; Coveney, 1973; Machairas, 1970). Some typical decrepigrams from gold mines in Australia and Canada are shown in figure 7, in which low temperature peaks caused by CO₂-rich inclusions are quite

prominent. The presence of these CO₂-caused peaks in the decrepigrams makes it difficult to estimate the T_h of primary inclusions. The work by Boyle (1954) at the Con mine, Yellowknife, Canada, which attempted to determine temperature zonation in quartz veins using decrepitation was troubled by the presence of these low temperature decrepitation peaks which are now (but were not then) known to be caused by CO₂-rich inclusions.

Forms of quartz other than veins are also amenable to decrepitation analysis. Decrepitation of chert samples has been useful in the mapping of many areas by clearly distinguishing the chert from quartz veins in the same area. This is particularly useful in drill core where

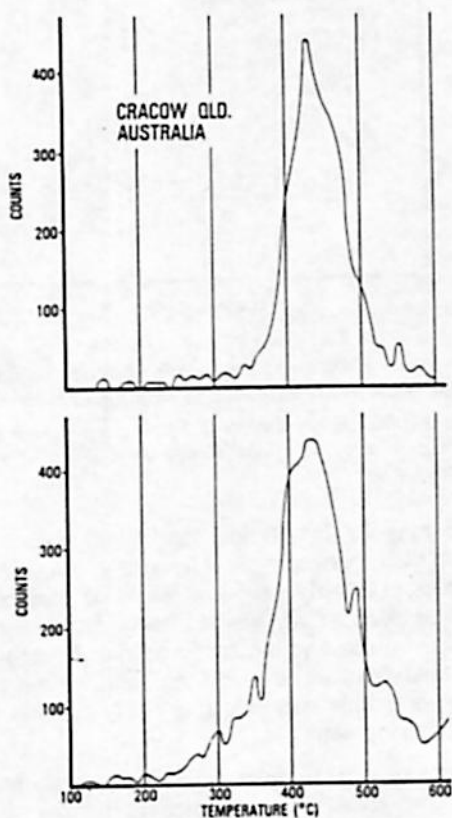


FIG. 6. — Similarity of decrepitation in quartz samples collected from more than 1 km apart at the Cracow gold mine, Qld.

Décrépitation d'échantillons de quartz pris à 1 km de distance à la mine d'or de Cracow, Qld.

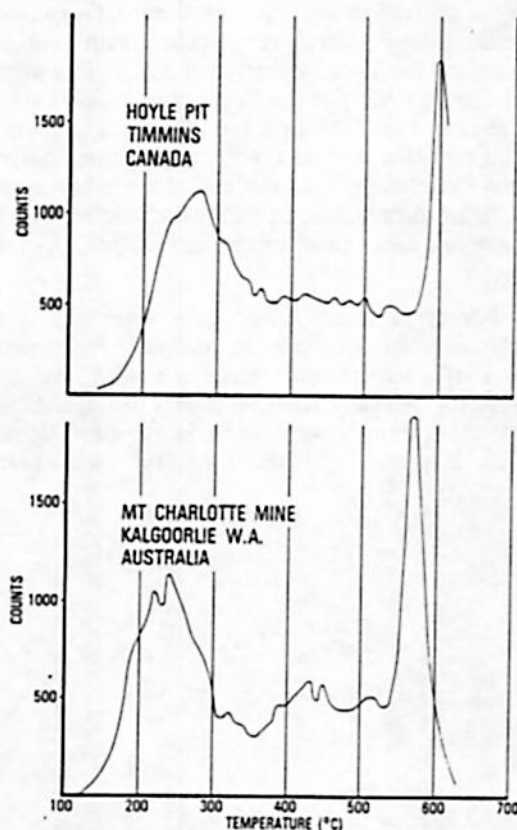


FIG. 7. — Prominent low temperature decrepitation due to CO_2 -rich inclusions in major gold mines.

Décrépitation dominante à faible température causée par des inclusions riches en CO_2 dans deux mines d'or.

there may be insufficient geological criteria to distinguish between these quartz types. Chert samples give only very low levels of decrepitation, or none at all, which clearly distinguishes them from most vein quartz material. Decrepitation analyses can also be done on silicified host rocks, a sample type which is rarely suitable for microthermometry.

Precious opal samples have also been decrepitated and these show distinctive, narrow, low temperature peaks (Figure 8). These decrepitations do not arise from fluid inclusions but from fluids in the interstices between the close packed silica spheres which comprise precious opal. The narrowness of the decrepitation peak is due to the great regularity in the sizes and packing of these spheres, which results in the

interstices having a very narrow size distribution.

2 - Magnetite and haematite

In the Tennant Creek area, N.T., Australia, several copper - gold mines occur within chlorite - magnetite - haematite rocks in which there are no transparent minerals suitable for microthermometry. The geology of one of these mines (Juno) has been described by Large (1975). The decrepitation technique has been used on the magnetite and haematite, both of which give good responses (Figures 9 and 10). Although there are marked differences between different samples of these minerals it was not

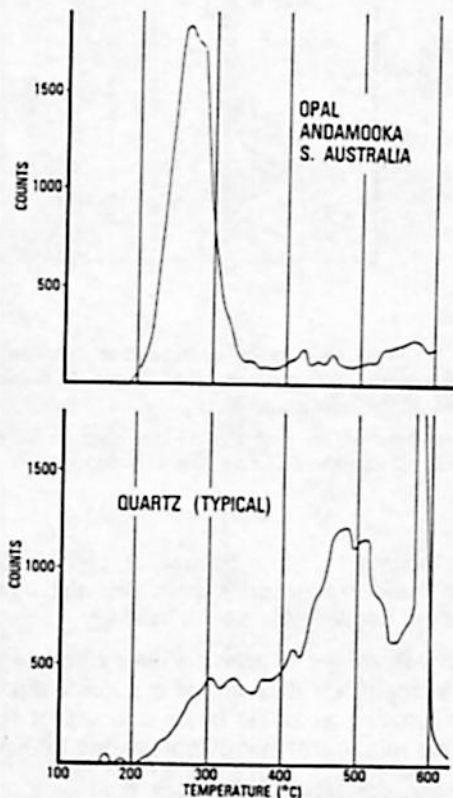


FIG. 8. — Very narrow decrepitation peak at low temperatures in precious opal, in contrast to the broader decrepitation peaks in typical quartz samples.

Pic de décrépitation très étroit dans l'opale précieuse comparé au large pic dans le quartz ordinaire.

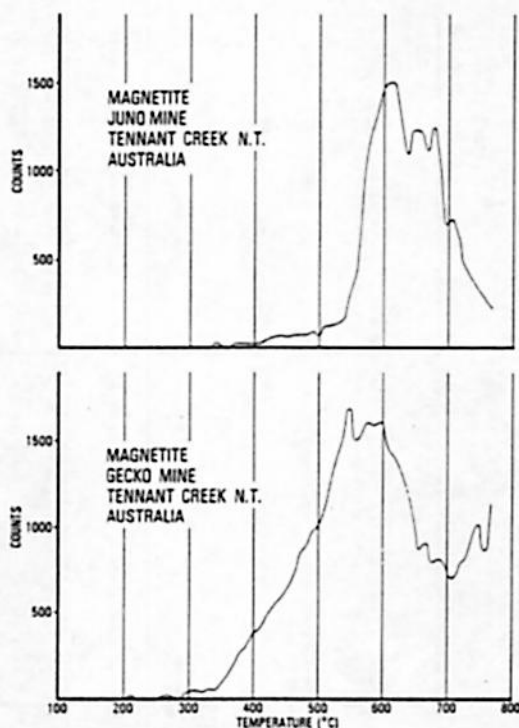


FIG. 9. — Typical decrepitation responses from magnetite samples in the copper-gold mines at Tennant Creek, N.T.

Décrépitation dans la magnétite dans la mine Cu-Au de Tennant Creek, N.T.

possible to relate these differences to the known mineralisation. Both the magnetite and haematite show quite high decrepitation temperatures which suggests that these deposits are of hydrothermal origin, although some geologists currently consider that they are sedimentary syngenetic deposits. The occurrence of decrepitation in haematite suggests that the haematite is of primary origin rather than having been derived by weathering of magnetite, as this process would have destroyed the fluid inclusions. Despite a lack of understanding of the cause of decrepitation in these minerals, the technique could be useful as an empirical exploration tool.

3 - Sulphides

Various sulphide minerals have been used in decrepitation studies including arsenopyrite, chalcopyrite, galena, pyrite, pyrrhotite and

sphalerite, all of which can give good decrepitation responses. The only problem is that sulphides start to oxidize or decompose at higher temperatures.

Sedimentary pyrite samples do not decrepitate at all whereas hydrothermal pyrite gives a good

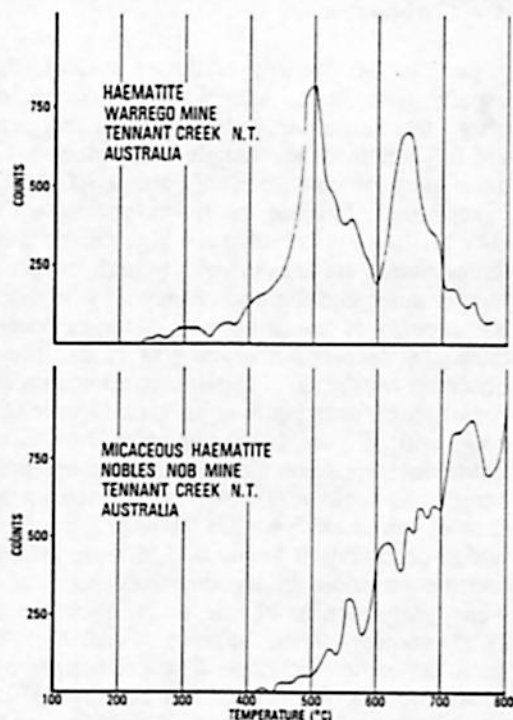


FIG. 10. — Typical decrepitation responses from haematite samples in the copper-gold mines at Tennant Creek, N.T.

Décrépitation dans l'hématite dans la mine Cu-Au de Tennant Creek, N.T.

decrepitation response. This has been used to elucidate the origin of different samples of pyrite. Although galena is ductile and might be expected not to decrepitate at all, it does give rise to a decrepitation response. Galena samples from the Pine Point and Sullivan deposits in Canada give low decrepitation responses while at the Woodcutters mine, N.T., Australia, samples of galena show very variable levels of decrepitation, sometimes quite intense, and no reason for this variability is apparent. Sphalerite samples give similarly variable decrepitation responses, which do not correlate with results from adjacent galena samples. All of these deposits are of

sedimentary origin and the decrepitation responses and temperatures ranging up to 500 °C are unexpected, perhaps being influenced by subsequent deformation events and the physical characteristics of the host minerals.

4 - Carbonates

Despite the ductility of the carbonates, they usually give intense decrepitation responses and often decrepitate violently, throwing fragments the full length of the sample tube. Most carbonates start to decrepitate only above 300 °C and give broad, intense peaks extending up to 800 °C. It is unlikely that the high decrepitation temperatures are due to equally high formation temperatures and the discrepancy may be due to the ductility of the carbonates. Some carbonates thermally decompose below 800 °C and this is observed on the decrepigrams as a very sudden cessation of decrepitation. In a study near Cracow, Qld. (Figure 11) the samples showed variable decomposition temperatures, some not decomposing below 800 °C. X-Ray diffraction studies on these samples showed that those which decomposed below 800 °C were ankerite and the variations in decomposition temperature were interpreted to be due to variations in the Fe^{2+} content of the ankerite (Hladky, 1985, personal communication). The exothermic oxidation of this Fe^{2+} promotes the thermal decomposition of the carbonate, which destroys all the fluid inclusions still present in the sample. Changes in the thermal decomposition temperature may therefore be useful in exploration as a guide to the composition of the carbonate.

VI. SUMMARY

Although there is a substantial amount of fluid inclusion data available on numerous ore bodies, little of this knowledge has been used to aid exploration. The decrepitation method aims to provide a fast and cost effective method of using fluid inclusion data to enhance mineral exploration programmes. It has also become apparent during this work that decrepitation data can be of use in complementing the microthermometric methods in research work on existing deposits.

In exploration, decrepitation holds hope of

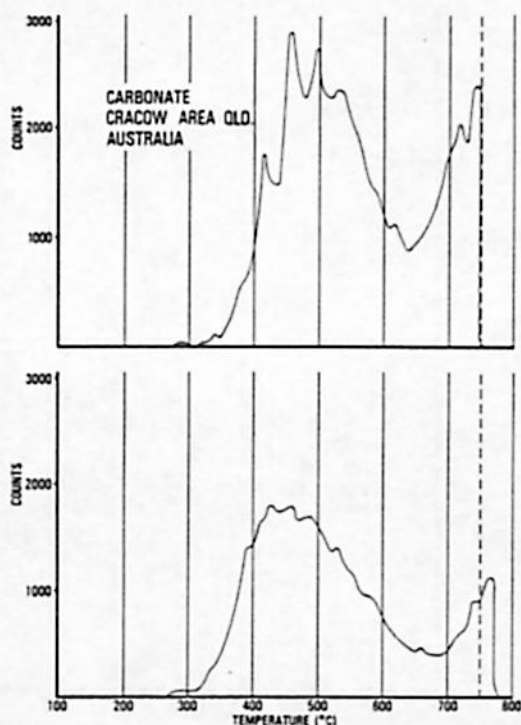


FIG. 11. — Sudden cessation of decrepitation at 750 °C (upper) and 770 °C (lower) in carbonate samples, due to thermal decomposition promoted by exothermic oxidation of Fe^{2+} . The temperature difference is due to variations in the Fe^{2+} content.

Cessation soudaine de la décrépitation à 750 °C (en haut) et 770 °C (en bas) dans des échantillons de carbonate, causée par la décomposition thermique favorisée par l'oxydation exothermique de Fe^{2+} .

being able to provide palaeothermal contour maps of large areas so that thermal centres can be pinpointed. This requires that large numbers of samples be analysed on a closely spaced grid and hence the analyses must be of low cost. To date it has not been possible to carry out the necessary orientation surveys to demonstrate this procedure to industry, although some work is currently being done along these lines.

Much use has been made of the ability to distinguish between different generations of quartz veins in an area. This has been applied to tin exploration (Burlinson *et al.*, 1983) where it was possible to distinguish between the mineralised and unmineralised veins. Similar distinctions between different vein generations have been made at some gold mines. Attempts to de-

fine zoning within vein systems have not been successful to date, either because the veins seemed too uniform over the distances sampled (Cracow, Qld; Cœur d'Alene, Montana) or because the small scale differences due to growth zoning made it impossible to distinguish any large scale lateral zoning (Pine Creek, N.T.).

The most important exploration use to date has been the ability to quickly recognise the presence of CO₂-rich fluids. Such CO₂-rich fluids occur commonly in auriferous veins but are far less common in tin bearing systems. Simply mapping out zones of high CO₂ content can be a useful gold exploration technique. Smith and Kesler (1985) have also pointed out the importance of mapping out zones of CO₂-rich fluids based on their studies at the Hollinger gold mine, Timmins, Canada, where they used gas chromatography to analyse CO₂ in the emanations from thermally decrepitated inclusions.

As a research aid, decrepitation can be used to preselect samples for detailed study. This may well avoid the preparation of many unusable polished sections lacking suitable inclusions for microthermometric study. It has also been useful in checking the results from prior microthermometric work. In one study an unusually large discrepancy between the decrepitation and microthermometric data led to a re-examination of the thin section and the realisation that some secondary inclusions had been mis-identified as primary inclusions. The decrepitation method also makes it possible to do a quick check for the presence of CO₂-rich fluids more reliably than by using microthermometry.

The decrepitation method invariably collects data from a very large number of inclusions per sample, far more than is possible in microthermometric studies. This provides far more reliable information on the number of inclusion populations present and the abundances of each inclusion type. By using the decrepitation and microthermometric methods together it is possible to undertake larger studies with greater confidence than if either method were used alone.

VII. CONCLUSIONS

Although the decrepitation method still suffers from the accuracy limitations that plagued its use in the late 40's and early 50's, the progress currently being made in our understanding of the decrepitation phenomena is improving our ability to interpret decrepigrams. The decrepitation method has the considerable advantages of being quick, cheap and applicable to many minerals, including opaques, as well as providing counts of a statistically meaningful number of inclusions per sample and requiring only minimal sample preparation. It provides a means of applying the massive amount of important fluid inclusion data to the problems of mineral exploration.

ACKNOWLEDGEMENTS

The author is grateful to G. Hladky and R. Wilkins for their continuing tolerance, assistance and helpful discussions.

REFERENCES

- BOYLE, R.W. (1954). — A decrepitation study of quartz from the Campbell and Negus-Rycon shear zone systems, Yellowknife, Northwest Territories. *Geol. Surv. Can. Bull.*, 30, 1-20.
- BURLINSON, K. (1984). — Exploration for gold at Pine Creek and Tennant Creek, N.T. and at Halls Creek, W.A. using the fluid inclusion decrepitation technique. *Aust. I.M.M. Darwin Conference*, 1984, 373-375.
- BURLINSON, K., DUBESSY, J.C., HLADKY, G. and WILKINS, R.W.T. (1983). — The use of fluid inclusion decrepitation to distinguish mineralised and barren quartz veins in the Aberfoyle tungsten mine area, Tasmania. *J. Geochem. Explor.*, 19, 319-333.
- COVENEY, R.M. Jr. (1973). — Fluid inclusion studies at the Oriental gold mine (abst.) *COFFI*, 6, 31.
- DANN, R.N. and DELANEY, W.R. (1984). — Geology of the Enterprise Mine, Pine Creek, Northern Territory. *Aust. I.M.M. Darwin Conference*, 1984, 407-413.
- GROSHENKO, A.R. (1973). — Notice of new instruments. *COFFI*, 4, 4-7.
- HLADKY, G. and WILKINS, R.W.T. (1987a). — A new approach to fluid inclusion decrepitation. *Practice. Chem. Geol.*, 61, 37-45.

- HLADKY, G. and WILKINS, R.W.T. (1987b). — An evaluation of fluid inclusion decrepitation using quartz from the Kingsgate molybdenite-bismuth deposits, New South Wales, Australia. In press, *Neus Jahrb. Mineral. Monatsh.*
- KOSTYLEVA, E.E. (1968). — Improvement in thermal-acoustic analysis. English translation in *COFFI*, 5, 125-129.
- LARGE, R.R. (1975). — Zonation of hydrothermal minerals at the Juno mine, Tennant Creek gold-field, Central Australia. *Econ. Geol.*, 70, 1387-1413.
- LEROY, J. (1979). — Contribution à l'étalonnage de la pression interne des inclusions fluides lors de leur décrépitation. *Bull. Minéral.*, 102, 584-593.
- MACHAIRAS, G. (1970). — The association of fluid inclusions and gold particles in auriferous quartz. *Schweiz. Mineralog. Petrog. Mitt.*, 50, pt. 1, 167-171 (in French).
- PULOU, R. and BAUDRACCO-GRITTI, C. (1978). — Un enregistreur décrépitation à filtrage électronique. *Bull. Minéral.*, 101, 402-405.
- SHAN LIN and ZHANG WENZHI (1979). — A study of double-decked vacuum glass isolating set of fire cracking instrument. *Geochimica*, 4, 340-342 (in Chinese).
- SCOTT, H.S. (1948). — The decrepitation method applied to minerals with fluid inclusions. *Econ. Geol.*, 44, 449-454.
- SMITH, F.G. (1950). — A method of determining the direction of flow of hydrothermal solutions. *Econ. Geol.*, 45, 62-69.
- SMITH, T.J. and KESLER, S.E. (1985). — Relation of fluid inclusion geochemistry to wallrock alteration and lithogeochemical zonation at the Hollinger-McIntyre gold deposit, Timmins, Ontario, Canada. *CIM Bull.*, 78, N° 876, 35-46.