Journal of Geochemical Exploration, 42 (1991) 143–156
Elsevier Science Publishers B.V., Amsterdam

Decrepitation in gold exploration. A case history from the Cotan prospect, N.T.

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(Received July 10, 1988; revised and accepted December 24, 1988)

ABSTRACT

Burlinson, K., 1991. Decrepitation in gold exploration. A case history from the Cotan prospect, N.T. In: S.E. Kesler (Editor), Fluid Inclusion Gas Analyses in Mineral Exploration. *J. Geochem. Explor.*, 42: 143–156.

The decrepitation method is capable of providing information on the abundance of CO_2-rich fluid inclusions in quartz samples by the observation of decrepitation at abnormally low temperatures (below 350°C). The method has been used in extensive regional and detailed studies in the Pine Creek goldfields, where a correlation between Au mineralisation and CO_2 content was observed by comparing analyses of samples from several existing operating mines with various other quartz samples from unmineralised areas throughout the region. An area of interest, defined by the regional scale sampling, was subjected to detailed study and this work delineated an anomalous zone with high CO_2 content which is closely related to a zone of low-level anomalous Au contents in quartz samples. The quartz shows highly variable decrepitation (and consequent CO_2 contents) over small distances, due to the presence of growth zoning and multiple stages of quartz emplacement, as is typical of a high level depositional environment.

INTRODUCTION

The decrepitation method has been used intermittently since its introduction in Canada by Scott (Scott, 1948). The method entails the measuring of acoustic emissions from a sample while it is heated at a controlled rate and plotting the data as a histogram of decrepitation counts versus temperature (a decrepigram). Although the accuracy is limited, the speed and low cost of the method make it ideal as an exploration technique for empirical comparisons between large numbers of samples, in the same manner as soil geochemical surveys. The analyses used in this study were carried out on a BGS model 04 decrepitometer (Burlinson, 1988a) which provides rapid, reproducible and reliable data. Some 4000 samples have been analysed to date on one of these instruments, providing case history data from a range of geological environments and locations.

Of primary interest in the work described herein is the observation that

0375-6742/91/$03.50

high CO_2 levels in the fluid inclusions in quartz samples lead to decrepitation at lower than usual temperatures, giving either a distinctive decrepitation peak between 150 and 350°C or a pronounced low-temperature skew to the decrepigram. Quartz samples lacking such CO_2-rich fluid inclusions give almost no response in this temperature interval (Burlinson, 1988a). Because of the known correlation between gold mineralisation and CO_2-rich fluids documented in many studies (Nash and Cunningham, 1973; Ho, 1987), the observation of such CO_2-induced decrepitation of samples has application in exploration for gold mineralisation.

In 1984, a suite of orientation samples was collected from the Enterprise gold mine, which is the largest producing mine in the Pine Creek goldfield, N.T. Additional samples for comparison were collected from old workings and unmineralised background areas throughout the goldfield. The decrepitation analyses of this initial suite of 47 samples showed the presence of low temperature decrepitation peaks on the samples from the mineralised areas while no such low-temperature decrepitation was observed on the background samples. One supposedly barren sample had a pronounced low-temperature decrepitation peak and an area surrounding it was subsequently chosen for detailed further investigation, and is the focus of the detailed work described in this study.

REGIONAL GEOLOGY AND MINERALISATION

Gold has been recovered from the Pine Creek goldfield area, N.T., since 1872 and there are presently about 6 major, producing mines (and many smaller ones) which produced about 4.3 tonnes of gold in 1987 from open cut and alluvial operations within an area of about 200 km by 100 km (Fig. 1). The area is comprised of Proterozoic sediments of the South Alligator and overlying Finniss River groups, intruded by syn- to post-orogenic granites. The South Alligator group includes greywackes, siltstones and tuffs with carbonaceous and haematitic sediments being quite common, whereas the Finniss River group is comprised dominantly of monotonous siltstones. The area is regionally metamorphosed to lower greenschist facies and is usually tightly folded. The carbonaceous and haematitic sediments in the South Alligator group are favourable depositional sites for gold mineralisation and are an important exploration target. However, several significant mines are located in the Finniss River group siltstones where no such chemical depositional traps occur and these deposits tend to be located in tightly folded anticlines (Goodall and Union Reefs areas).

All the known economic deposits occur close to the granites and within their contact-metamorphic aureoles, the Enterprise mine being within a particularly well developed contact-metamorphic aureole (Dann and Delaney, 1984) and only about 1 km from the granite outcrop. Other mines are more

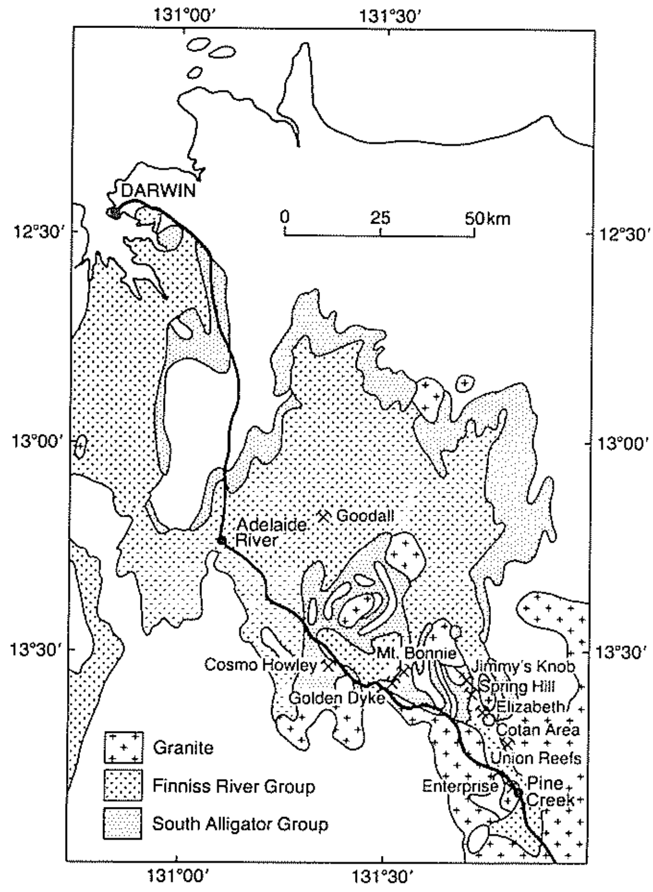

Fig. 1. Location map, Pine Creek region, N.T., with geology.

remote from granite outcrop but still within the contact-metamorphic aureole, an example being the Goodall mine which is 17 km from the nearest granite outcrop and within, but near the outer limit of the contact-metamorphic aureole.

Because of these similarities it is considered that the known deposits can all be explained as variations of a single model, in which fluid cells driven by heat from the granite intrusions have carried gold into the overlying sediments, where it has been deposited either in chemically favourable sites (the carbonaceous or haematitic horizons) due to pH and Eh changes, or concentrated in structurally complex areas where the deposition is due to temperature or pressure changes. The presence of CO_2-rich fluids in the mineralised samples is taken to confirm the concept of involvement of the granites in the mineralisation process as the regional metamorphic grade of lower greenschist facies is insufficient to release CO_2. The higher temperatures related to the granite intrusion are, however, capable of generating the observed CO_2-rich fluids. The granites are implicated only in their role as promoting transport of the gold in fluids and no data is available to deduce the actual source of the gold, which may have been derived from the granite, parts of the sedimentary pile or from volcanic exhalative units within the sequence (Nicholson and Eupene, 1984).

REGIONAL STUDIES

Initially, 47 samples were collected from the region, 24 of which were collected from significant gold mines, 5 from minor gold occurrences, 9 from a tin mine within the goldfield and the remaining 9 from unworked quartz veins, presumed to be barren background samples. These samples were crushed, sieved and analysed by decrepitation as described by Burlinson (1988a). To facilitate comparison of the decrepigrams, the total number of counts recorded in the temperature interval 150° to 350°C was used (Fig. 2). This is the temperature region in which CO_2-rich inclusions decrepitate and the sum value gives an indication of the abundance of such inclusions in the sample. It is thought that the CO_2-rich inclusions decrepitate at low temperature because of their internal pressures and because of the high thermal expansion coefficient of CO_2. Attempts to normalize this value to allow for variations in the total decrepitation response of each sample were unsuccessful and the logarithm (base 10) of the total number of counts from 150 to 350°C was found

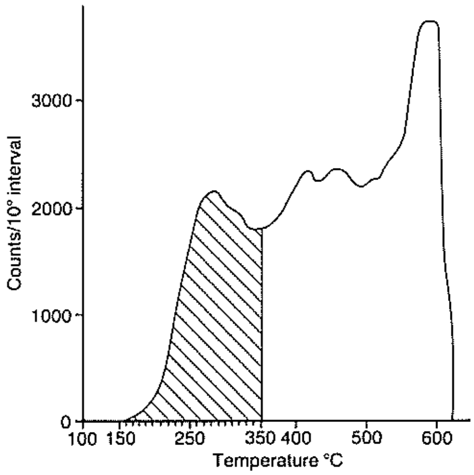

Fig. 2. An example decrepigram of a sample with abundant CO_2-rich inclusions, from the Enterprise mine. The total counts from 150 to 350°C (shaded area) is related to the abundance of CO_2-rich inclusions.

to be the most useful way of classifying the samples. Although this is an oversimplification of the relation between CO_2-rich inclusions and low-temperature decrepitation it was found to be a useful and simple interpretative procedure.

Nineteen of the samples were from the Enterprise gold mine where 5 stages of quartz veining have been recognized, based on structural considerations (Dann and Delaney, 1984). Of these, the two earliest stages are thought to have been formed prior to the gold mineralisation event. Because most of the samples were collected from drillcore it was not possible to allocate the decrepitation samples used in this survey to their particular vein stage and it was not therefore surprising that some samples lacked a low-temperature decrepitation peak, these presumably being samples from the pre-mineralization veins. This decrepitation data showed the importance of CO_2 in the fluid inclusions in this mine (Burlinson, 1984), a fact which had not been recognized in previous microthermometric studies.

The presence or absence of CO_2 in the inclusions was checked by microscope observations on 9 of the samples, 4 of which had prominent low temperature decrepitation peaks, 3 of which had almost no low-temperature decrepitation and the remaining 2 having minor low-temperature decrepitation. Standard petrographic sections were prepared and observed both at room temperature and on a thermoelectrically cooled stage at about 0°C. These observations, summarised in Table 1, confirm the relationship between the pronounced low-temperature decrepitation peaks and the presence of CO_2-rich fluid inclusions in the samples.

The data available in mid-1984 are shown in Fig. 3. This plot shows that CO_2-rich inclusions are more abundant in areas of known gold mineralisation and less likely to occur in background areas. In addition, other types of mineralisation such as the Jimmy's Knob tin deposit had relatively rare CO_2-

TABLE 1

Comparison of microscope and decrepitation data. Nine samples from the Pine Creek goldfield

Sample No.	Decrepitation counts, Total from 150–350°	CO_2-rich inclusions in microscope examination
PCE 17	26476	Abundant
PCE 15	47	None
PCB 5	83	None
PCSH 3	22655	Common
PCB 4	12005	Common
PCE 14	664	None
PCE 3	1486	None
PCB 7	1613	Rare or none
PCJK 7	3034	Present but uncommon

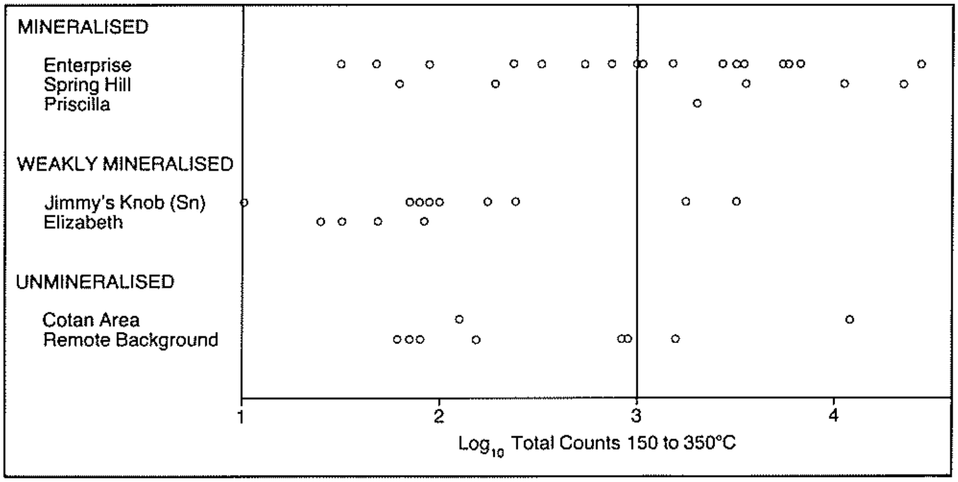

Fig. 3. Summary of results of 47 samples at mid-1984, showing a preferred relation between decrepitation response and gold mineralisation potential.

rich samples compared with the gold-mineralised areas. The background samples plotted in this diagram were collected from various readily accessible quartz outcrops within the goldfield, but upon which no old gold diggings were known. One of these background samples had a very high CO_2 level, indicating the presence of a CO_2-rich palaeothermal system in which no gold occurred in the quartz in present surface outcrop. On the theory that gold may have been deposited in such a system below the level of present day outcrop, it was decided to carry out detailed studies of the area surrounding this sample, as well as continuing to collect regional samples to check the relationship between the gold and low-temperature decrepitation activity. The area delineated for detailed work was named Cotan and the detailed work done there is described below.

The regional work continued by sampling many other mineralised areas throughout the goldfield and a total of 211 samples have now been collected. These are plotted in Fig. 4. This data further confirms the association between CO_2-rich fluids and gold mineralisation in this region, most of the currently producing mines showing an abundance of samples with total low-temperature decrepitation counts above 1000. Exceptions to this pattern occur at the Goodall and Davies mines, although their lack of CO_2-rich samples may be a function of the sampling pattern, both of these mines having been sampled at a time when the ore zones were not exposed in the pits.

Although samples remote from mineralisation lack significant levels of CO_2, some of the background samples collected near known mineralisation show unexpectedly high CO_2 levels. This is so in the area just north of the Enterprise mine, which has been classified as weakly mineralised in this figure,

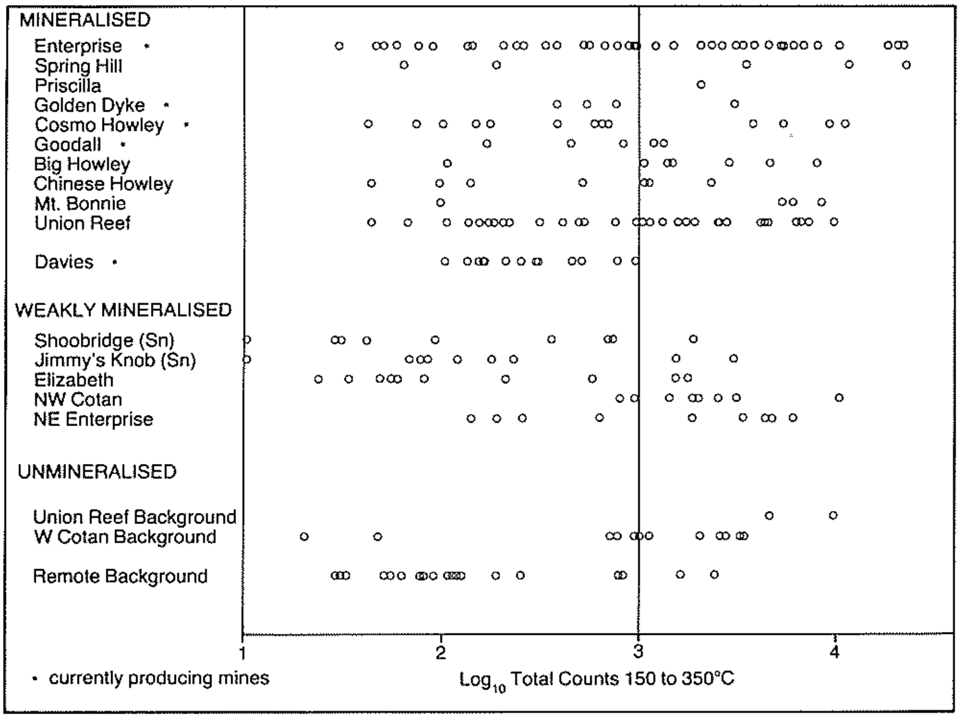

Fig. 4. Summary of results of 211 samples at late 1988. Mineralised areas are generally associated with CO_2-rich fluids.

although no workings are known on the quartz veins which were sampled. Other background samples collected near the extensive Union Reefs workings and near the Cotan area also contained high levels of CO_2-rich inclusions. These samples were some 2 to 3 km from the nearest known mineralisations and the presence of CO_2 in them suggests that there may be very large haloes around the mineralised areas. Such large CO_2 haloes have also been described at Timmins (Smith and Kesler, 1985).

The more thorough regional study data does confirm the relationship between gold mineralisation and the abundance of CO_2-rich fluid inclusions in the Pine Creek goldfield. However, because some presumed background samples collected near existing mines also had high CO_2 contents it is not possible to reliably discriminate between mineralised and barren veins on the basis of CO_2 content alone.

THE DETAILED STUDY AT COTAN

The Cotan area was selected on the basis of an unusually high abundance of CO_2-rich inclusions in a quartz outcrop within a belt known for its previous gold production. Although there were no old workings on the actual outcrop of interest, several workings occur nearby. The area selected for study was about 3 km long by 1.5 km wide, extending approximately north–south and parallel to the direction of the dominant structural features in the area.

The area is within the Finniss River group sediments and comprises siltstones and minor greywackes of the Burrell Creek formation. This formation lacks distinctive marker horizons and only one small lithological variation was mappable. The rocks strike northwesterly at 325 to 335° with near-vertical dips. There is a strong pervasive axial plane foliation oriented at 325° and with near vertical dip, together with evidence of cross shearing in several different directions. The Cotan area is within the Pine Creek shear zone which extends for approximately 50 km and within which may other gold occurences are located, including the nearby Union Reef and Spring Hill deposits.

An anticlinal fold axis runs through the Cotan area but is recognizable only from observation of the bedding-cleavage intersection angles due to the lack of distinctive lithological horizons. A few kilometers to the north, complex folding has been recognised where varying lithologies facilitate the mapping and it is reasonable to expect the Cotan area to be similarly folded. These fold axes plunge southwards at approximately 10 to 15°.

Quartz veining is common throughout the area, frequently occurring as lenses up to 5 cm thick and also as massive large quartz veins. Although *in situ* outcrop of quartz is not always available, quartz rubble (fragments 1–3 cm across) is common. The soils are skeletal and residual and it is not therefore likely that the coarse quartz rubble has been transported. The most likely origin for the quartz is from the discontinuous lensoid quartz veins which are ubiquitous in the bedrock, though they outcrop only poorly.

Geophysical and sampling surveys were carried out to explore the area. The geophysical surveys (magnetics and EM methods) were not useful and are not discussed here. The sampling work involved collection of rock samples (mostly of quartz) for routine geochemical analysis and also for decrepitation analysis. The sample sites were located on aerial photographs and were all sampled for decrepitation, with geochemical analyses of only selected sites. The geochemical assay samples were comprised of multiple rock (usually quartz) fragments 2–4 cm across, totalling about 1.5 kg and collected within a radius of about 1 metre. For the decrepitation analyses, a single piece of quartz about 3–4 cm across was collected at each site. The decrepitation results showed considerable variation between samples collected within centimetres of each other so in subsequent sample collection programmes, 2 or 3 quartz lumps were collected within a metre of each other at each site and analysed separately in order to observe these variations. Such inhomogeneity in the quartz is common in many areas (Burlinson, 1988b) and is due to growth zoning and multiple depositional episodes which are common features in high level deposits.

After collecting and analysing 189 samples, the data were plotted as a cumulative frequency graph (Fig. 5). This was rather irregular, but it appeared to be the result of 3 overlapping populations. The characteristics of the 3 constituent populations were derived using the methods described by Sinclair (1976). Using the 2% cumulative frequency points for each population, ranges of decrepitation values were selected which correspond either to individual populations or to overlap of 2 of the populations. The decrepitation values selected are listed in Table 2 and these threshold values were used in the subsequent interpretation to define the levels considered to be anomalous. At a later date, after 274 samples had been analysed, the cumulative frequency graph was recalculated on the enlarged data set and this is shown in Figure 6. This differs markedly from the previous graph, despite the fact that 70% of the data used in its derivation is the same. It was not possible to split this graph into constituent populations with any degree of confidence. This indicates that the previous selection of threshold values is not ideal, but as no better selection was possible, those values were used throughout the interpretation of the results.

Where multiple samples were collected at a site, there was not usually any difference visible in hand specimen between the quartz fragments collected. However, the decrepitation results were often markedly different, variations

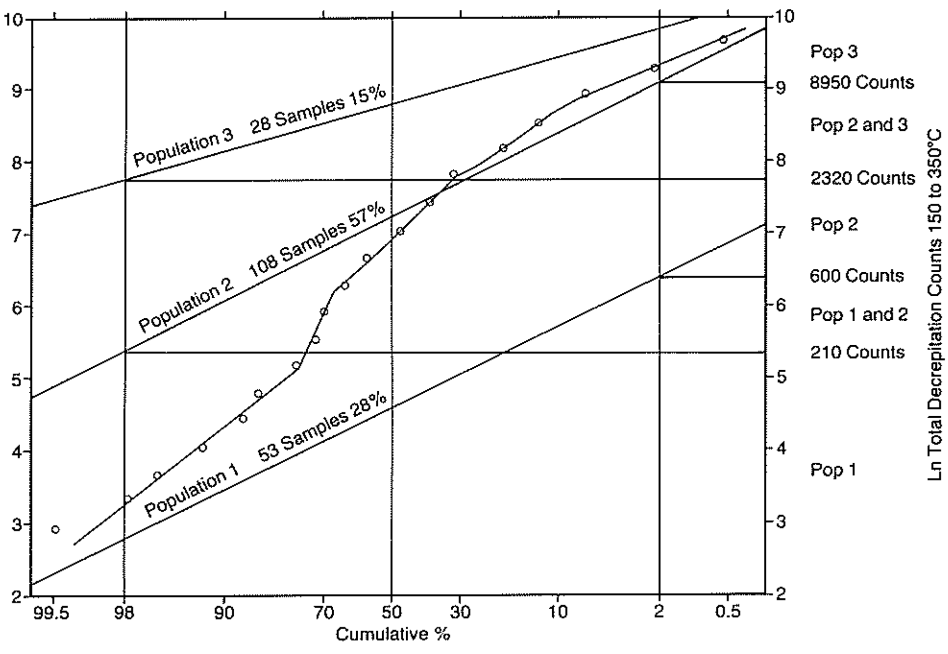

Fig. 5. Cumulative frequency plot of 189 samples in 20 intervals, 1986. Three populations are distinguished and used for selection of thresholds.

TABLE 2

Threshold levels for anomaly selection of the decrepitation data. Based on 189 samples, grouped into 20 class intervals.

Range of decrepitation counts	Population(s)
>8900	Predominantly population 3 (upper)
2300 to 8900	Overlap of populations 2 & 3 (60% pop. 2 and 40% pop. 3)
600 to 2300	Predominantly population 2 (middle)
210 to 600	Overlap of populations 1 & 2 (30% pop. 1 and 70% pop. 2)
<210	Predominantly population 1 (lower)

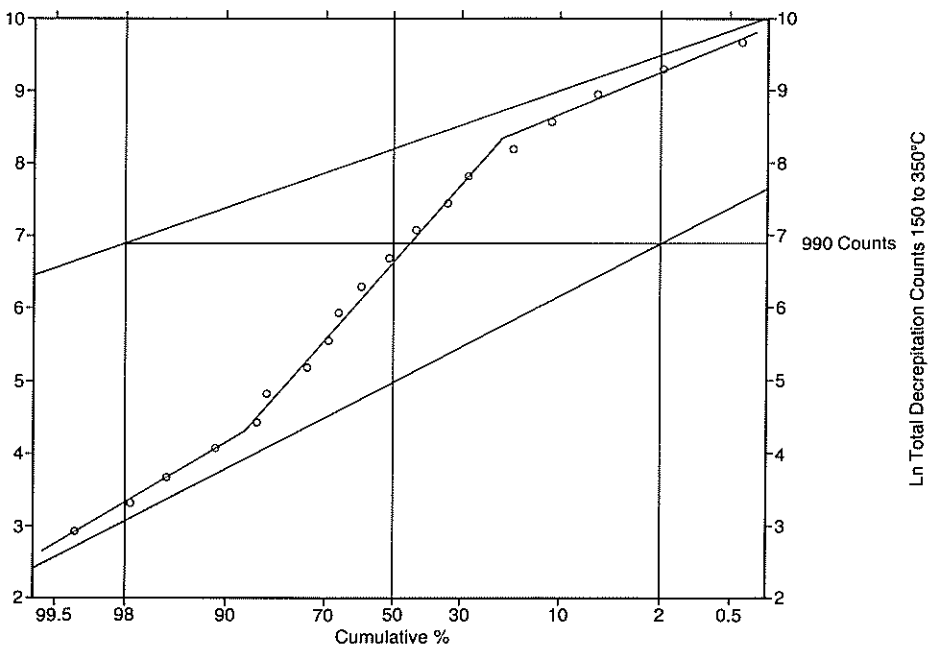

Fig. 6. Cumulative frequency plot of an enlarged set of 274 samples in 20 intervals, 1988. There are several overlapping populations and it is difficult to break the data up into its component populations.

from 200 counts to 11,000 counts between samples only 1 metre apart being observed. The long-term analytical reproducibility of the instrument is better than 5% (Burlinson, 1988a) and the variations are not the result of analytical problems but reflect original differences in the samples. Such differences are due to multiple stages of quartz vein emplacement and growth. The recognition of these depositional conditions is in itself useful as it indicates a high-

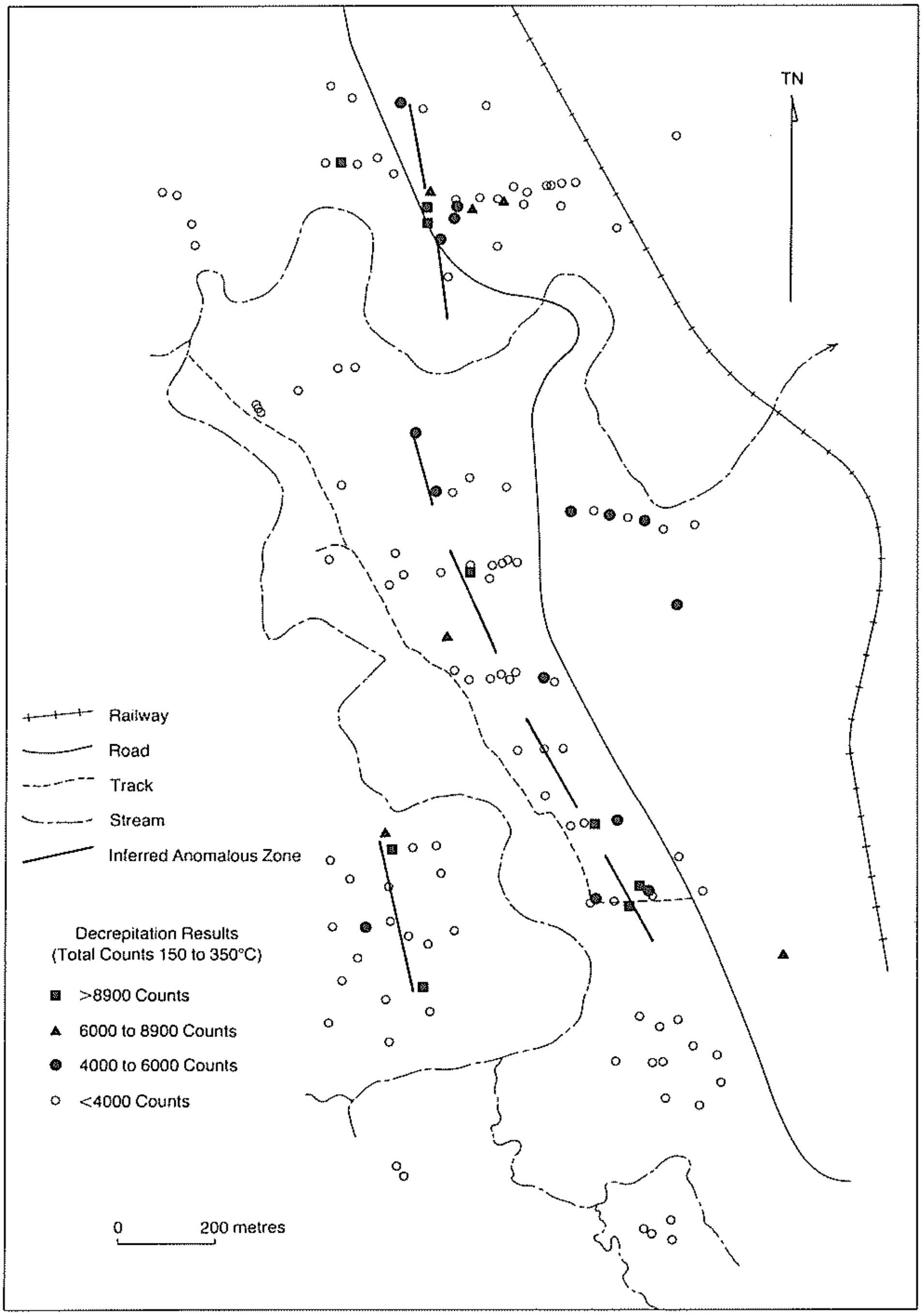

Fig. 7. Decrepitation results at the Cotan area. Where more than one analysis was done at a site, the highest result is shown here.

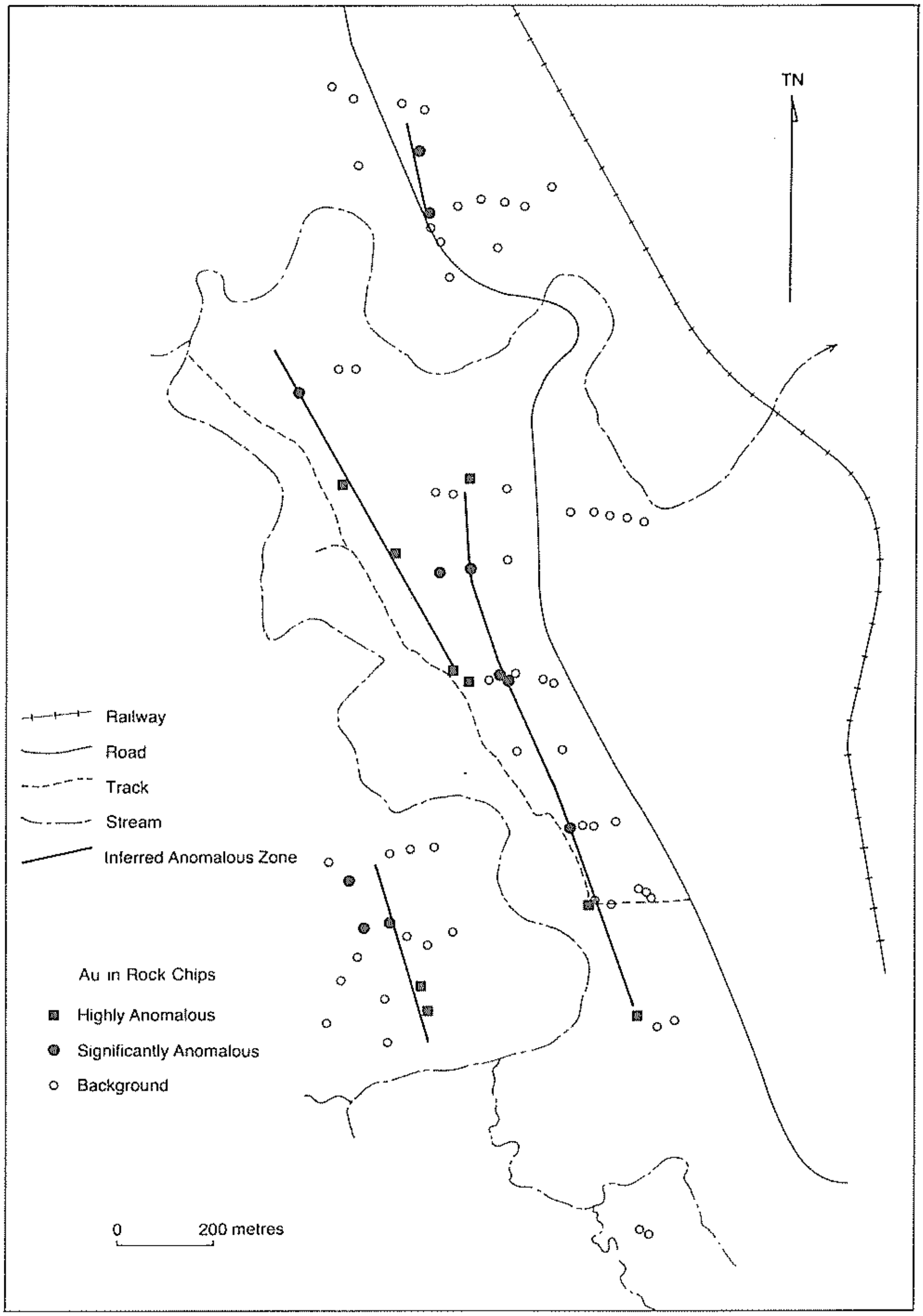

Fig. 8. Gold analysis in rock chip samples at the Cotan area. The inferred anomalous zone is near to but not coincident with the anomalous decrepitation zone.

level environment and this can rarely be discerned by mere visual mapping of the quartz.

Some 300 samples from the Cotan area have now been analysed by decrepitation and the results are summarised in Figure 7. To simplify the diagram, only the separate sample sites are shown although there are 2 or 3 analyses at most sites. The decrepitation count value plotted is the maximum of the analyses at that sample site. The use of the maximum rather than an average result is in accordance with the results of the regional work discussed above, however, another plot using the average of all results at each site was also prepared. This gave rise to the same pattern of anomalies, but with lower contrast and less precise definition. The similarity of the 2 plots serves to confirm that the anomalous zone shown in Figure 7 is real and not merely a function of the method of presentation or interpretation of the results.

Although the decrepitation results do not define a perfectly continuous zone, when considered together with the geological structure of the area it is reasonable to interpolate an anomalous zone almost the full length of the study area, together with a parallel zone to the west of the river.

The rock geochemical samples were analysed either using fire assay or aqua regia digestions, with determination by atomic absorption spectophotometry. The dual assay methods were used as the presence of sulphides in some samples precluded the use of the aqua regia technique. Despite the mixed analytical methods, the results (Fig. 8) show a low-level gold anomaly in quartz which is parallel and close to (but not coincident with) the decrepitation anomaly. Anomalous samples have gold contents of 20 to 500 ppb while background levels are less than 20 ppb. The anomalous samples often, but not always, contain anomalous levels of arsenic.

These anomalous zones have not yet been tested by further exploration, which is continuing in the area.

CONCLUSIONS

At the regional scale of exploration, the decrepitation results assisted in the recognition of zones of anomalous CO_2-rich fluids and thereby pinpointed areas of interest for subsequent gold exploration. Although the method was useful in the Pine Creek goldfield where most deposits are of similar origin, it would be more difficult to apply in more complex geological settings. The detailed local decrepitation study at the Cotan area has outlined a zone of anomalous CO_2 contents in fluid inclusions. The significance of this zone is confirmed by the presence of a nearby low-level gold geochemical anomaly in rock samples.

The concept of using the gas content of fluid inclusions as an exploration method permits the evaluation and targetting of areas where potentially mineralised fluids have occured, but where the gold that these fluids may have carried was not deposited in the rocks which are currently exposed. It is therefore possible to recognize these systems in present (gold barren) outcrop and explore them down dip where the conditions for gold deposition may have been more favourable. In the exploration for bonanza deposits such as those at Colqui (Kamilli and Ahmoto, 1977) it is quite possible that barren veins in present outcrop are strongly mineralised at depth at the level where CO_2 effervescence, boiling or wall-rock interactions may have resulted in the extraction of gold from the fluid system. Exploration methods relying on gas contents of fluid inclusions are one of the few ways of recognising such potentially important mineralised systems and the decrepitation technique is one method of applying such gas data in exploration.

ACKNOWLEDGEMENTS

The author thanks Venture Exploration for permission to publish data on the Cotan area and for their cooperation during the study.

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