CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA
BULLETIN 30

A DECREPITATION STUDY OF QUARTZ FROM THE CAMPBELL AND NEGUS-RYCON SHEAR ZONE SYSTEMS, YELLOWKNIFE, NORTHWEST TERRITORIES

BY
R. W. Boyle

EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1954.

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PREFACE

Detailed studies of liquid inclusions within the quartz of gold-bearing veins of a number of gold mines and prospects in Canada have been completed during the past 5 years. In these studies quartz of the vein is crushed and heated to cause the liquid in the inclusion to expand to the point of breaking the containing quartz, and the temperature at which this happens is interpreted as the approximate temperature of formation of the inclusions and in some cases the approximate temperature of formation of the quartz. This and other facts about the quartz veins gained in such investigations give clues that may be interpreted to suggest the probable source and direction of movement of the gold-bearing solutions from which the ore formed and thereby assist exploration and development of the mine or prospect by directing attention to locations regarded as of special interest.

The investigation, the results of which are described in this bulletin, was undertaken to further this research and to assist operators in the Yellowknife area where development of promising gold deposits was commenced in 1937. The quartz of the veins and the occurrence in it of the gold and liquid inclusions are described in some detail. Several hundred readings of the temperature at which the expansion of the liquid in the inclusions caused the quartz to break (decrepitate) were made and averaged. The report provides considerable information on the quartz veins from the Negus and Rycon mines and indicates also that the changes the quartz had undergone since it was originally deposited must be taken into account when the decrepitation method is used.

GEORGE HANSON,
Director, Geological Survey of Canada

OTTAWA, April 14, 1954

A DECREPITATION STUDY OF QUARTZ FROM THE CAMPBELL AND NEGUS-RYCON SHEAR ZONE SYSTEMS, YELLOWKNIFE, NORTHWEST TERRITORIES

INTRODUCTION AND PURPOSE OF THE STUDY

This study was suggested by the National Advisory Committee on Research in the Geological Sciences and was undertaken by the author as part of an extensive geochemical investigation of the gold ore deposits of the Yellowknife greenstone belt.

The purpose of the study was to obtain maps showing the temperatures at which the quartz decrepitates in the orebodies and barren parts of two typical shear zone systems, and, if possible, from these data to determine the direction of flow of the mineralizing solutions and hence predict the location of ore shoots.

Field work was carried out at Yellowknife during the summers of 1950, 1951, and 1952. Laboratory work on the samples collected in the field was done between field seasons in the geochemical laboratory, Department of Geological Sciences, University of Toronto.

The author wishes to thank Dr. F. G. Smith for guidance, discussion, and criticism during this study. Dr. J. F. Henderson read and criticized the paper, and to him the writer is most grateful.

FIELD AND LABORATORY METHODS

During field work the accessible underground workings along the shear zones of the Campbell and Negus-Rycon systems were examined, and samples of quartz were collected from ore shoots and barren sections of the shear zones. All sample locations together with pertinent geological data were plotted on plans and sections of the Negus and Rycon mines.

In the laboratory the barren and gold-bearing quartz was studied in hand specimens and thin sections. Samples were then crushed, screened, and decrepitated in the quartz decrepitation analyser, and the decrepitation temperatures were recorded.

The laboratory study of quartz by decrepitation methods has been described by Scott (1948[1]), Smith and Peach (1949a), Peach (1949), and Smith and Peach (1949b). The reader is referred to these published accounts for a detailed description of the methods and apparatus in use.

In general, quartz contains two types of liquid inclusions. These have been called primary inclusions and secondary inclusions depending upon their nature and location in the quartz crystals and grains. Primary liquid inclusions occur along growth planes, interlineage boundaries, and other crystal discontinuities and are thought to have resulted by the trapping of some of the fluid from which the quartz grew. Secondary liquid inclusions occur along healed fractures, around grain boundaries, and in small, clear, crosscutting (phantom) veinlets. In most thin sections of vein quartz, trains of secondary inclusions cut across grain boundaries, and hence appear to have formed by the trapping of some liquid from solutions migrating along grain boundaries and fractures that formed after the deposition of the quartz crystals and grains.

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[1] Dates, etc., in parentheses are those of References, page 20.

At the temperature and pressure of formation of both primary and secondary inclusions the trapped liquid would just fill the inclusions. During the drop in temperature and pressure to that prevailing in the rocks where the quartz is now found, the liquid contracts, and small vapour bubbles (vacuoles) form within the inclusions. These inclusions with their vapour bubbles can be seen under high magnification in nearly all quartz grains and crystals.

If the quartz is slowly heated, the liquid in the inclusions expands to refill the inclusion and the vacuole disappears (the filling temperature). Further heating produces pressure in excess of the tensile strength of the quartz, and the liquid breaks the quartz with a "pop", that is, the quartz decrepitates. The temperature at which the quartz decrepitates is known as the decrepitation temperature. The difference between the filling temperature and decrepitation temperature is called the over shoot in temperature.

Three methods have been developed to determine the filling temperature:

(1) The original optical method of Sorby (1858), consisting of measuring the diameter of the inclusion cavity and vacuole, converting the relative diameters to relative volumes, thus giving the degree of filling, and utilizing tables of pressure-temperature-volume of water to estimate the filling temperature;

(2) a direct optical method utilizing a heating-stage mounted on a high-power microscope through which an operator observes the disappearance of the vacuoles in the inclusions, measuring the filling temperature by thermometer or thermocouple;

(3) the modern decrepitation geothermometer consisting of an electrically heated oven in which a specific quantity of clean crushed quartz is placed and heated at a controlled constant rate. The miniature explosions or "pops" of the decrepitating quartz are picked up by a sensitive microphone, amplified, fed to an electronic integrating mechanism and then to a recorder that draws a curve of decrepitation rate versus time. Because the heating rate in degrees per minute is rigidly controlled the time co-ordinate is in effect a temperature co-ordinate. Figure 1 shows a typical ideal decrepitation curve obtained by this method. The curve shows two decrepitation temperatures, one at 162°C. probably due to secondary inclusions, and another at approximately 300°C. probably due to primary inclusions. To determine the filling temperature from these temperatures the over shoot in temperature must be subtracted.

It should be pointed out that the filling temperature of the liquid inclusions does not represent the mineral crystallization temperature that prevailed during the formation of the liquid inclusions. To obtain the crystallization temperature, either an estimated pressure correction or a pressure correction determined by some other geothermal method (e.g., pyrite geothermometer, Smith, 1947) must be applied to the filling temperature.

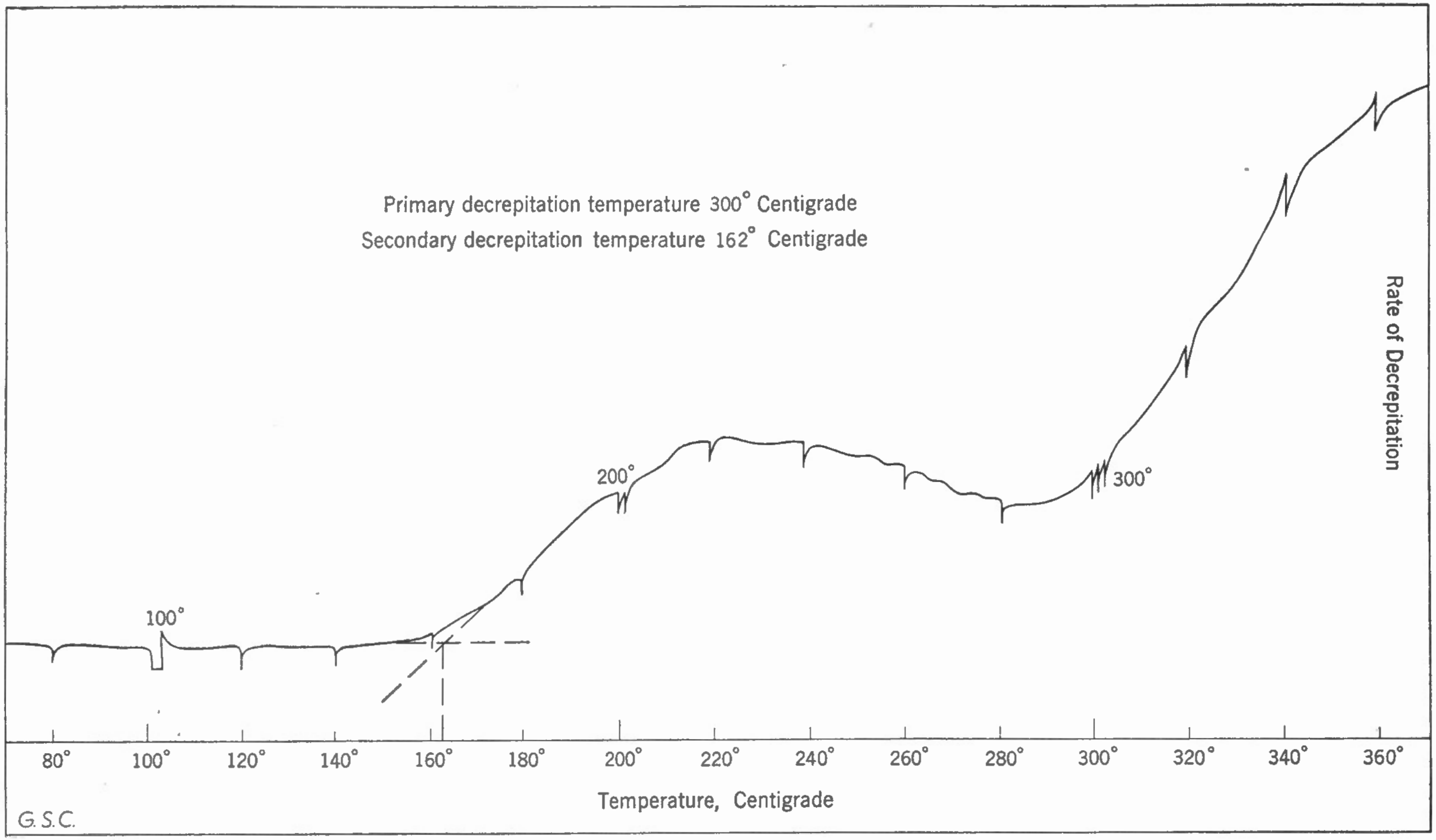

Figure 1. Typical quartz decrepitation curve showing method of selecting the secondary decrepitation temperature.

During the laboratory determination of the decrepitation temperatures of the quartz given in this bulletin, all possible factors were kept as constant as possible. Optimum conditions to give good decrepitation curves for the type of quartz from the deposits were investigated and found to be as follows:

Volume of quartz per run	1 cc.
Size of quartz grains	crushed and sieved to —40 +80 mesh
Heating rate	10°C. to 20°C. per minute

Carbonate minerals, mica, and other minerals that might interfere with the results were removed from the samples by either leaching with hydrochloric acid or hand picking.

The decrepitation temperatures that are shown on the longitudinal sections accompanying this bulletin (Figures 8B, 8C, 9B, and 9C) have been read from the curves by extrapolating the steep part of the curve back to the intersection with the base line and taking the point found as the instrumental decrepitation temperature. The method is illustrated in Figure 1 for the secondary decrepitation temperature. These temperatures were then corrected for instrumental lag effects according to the quartz calibration carried out by F. G. Smith in October 1950.

The intensity of decrepitation values shown on the longitudinal sections (Figures 8B, 8C, 9B, and 9C) are measures of the slope of the first curve obtained (secondary decrepitation temperature curve). The values are approximate and correspond to the intensities shown below.

Intensity index	Slope of curve	Intensity
1	Low	Feeble
2	Moderate	Fair
3	Moderate to steep	Good
4	Steep	Strong
5	Steep to vertical	Very strong

In this investigation only the first curve obtained from the instrument, that is, the secondary decrepitation curve, was used, and hence all temperatures shown are secondary decrepitation temperatures. No corrections for pressure have been applied to these temperatures. Primary decrepitation temperatures were obtained for many samples, but the interpretation of the curves proved too difficult for the time available for the research. As will be described later, there are reasons to suggest that the secondary decrepitation temperatures are the most significant as regards gold deposition, and research was directed to determining these temperatures in detail.

GEOLOGICAL ENVIRONMENT OF QUARTZ BODIES

The gold-bearing quartz veins and lenses of the Yellowknife greenstone belt occur within shear zones in steeply dipping flows of metamorphosed andesite, basalt, and dacite of Archæan age. Of the shear zones, those carrying gold orebodies are grouped in three systems known as the Con, Giant-Campbell, and Negus-Rycon systems. The nature and pattern of the three systems have been described in detail in two previous papers (Boyle, 1954).

The investigation described herein was carried out on the orebodies of two of the above shear systems. The orebodies, now mined out, of the Negus and Rycon mines were chosen as typical of those occurring in the Negus-Rycon system, and the orebodies of the Negus mine (Campbell system)[1] were chosen as typical of those occurring in the Giant-Campbell and Con systems.

The Giant-Campbell shear zone system consists of several wide interlacing shear zones separated by horses and masses of slightly altered country rock. Chlorite schist with variable foliation comprises the shear zones where the effect of mineralization is weak or absent. Where lenses and veins of quartz are present in the chlorite schist these are bordered by a characteristic alteration halo wherein an adjacent carbonate-sericite zone grades outward into a chlorite-carbonate zone and this into the chlorite schist.

The Negus part of the Giant-Campbell system was chosen for study because the orebodies here are well defined and have been mined to a depth of 2,200 feet. Figure 8A illustrates the nature of the shear zone system and the distribution of the ore shoots on the 1,775-foot level of the Negus mine. Figure 8B is a projection of the ore shoots on a longitudinal section in the plane of the hanging-wall of the productive shear zone.

The Negus-Rycon system consists of several narrow ramifying shear zones that branch and join throughout their extent. The principal shear zones are seldom more than 5 feet in width and are composed of chloritic breccia and schist where the effects of mineralization are weak or absent. As in the Giant-Campbell system, quartz veins and lenses have an alteration aureole that comprises an inner carbonate-sericite zone and an outer carbonate-chlorite zone that grades imperceptibly into the chlorite rock of the shear zone. Figure 9A illustrates the underground geology and location of the quartz lenses in the Negus mine (Negus-Rycon system). Figures 9B and 9C illustrate the distribution of the ore shoots on a longitudinal section in the plane of the N-1, N-9, N-15, and R-51 shear zones, and the N-3 and R-57 shear zones respectively.

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[1] The Giant-Campbell system is faulted into two segments by the West Bay fault. The southern faulted extension is called the Campbell system.

PETROGRAPHIC DESCRIPTION OF QUARTZ

CAMPBELL SYSTEM

This system of shear zones contains quartz of two distinct ages. The older or early quartz is white to faintly flesh coloured and occurs in large, irregular, lens-like, composite bodies throughout the carbonate-sericite schist of the shear zones. The younger or late quartz occurs in narrow quartz-carbonate stringers and veinlets that cut across and have sharp boundaries with the earlier quartz and its bordering alteration zones. Stringers and veinlets of the late quartz are abundant and occur almost exclusively within the highly altered parts of the shear zones.

The early quartz, of the orebodies, grades into the adjacent quartz-sericite-carbonate schist across a zone of sulphide-bearing sericite schist a few inches to a foot or more in width. In some lenses of quartz ribbon structures are characteristic and in others the quartz is nearly massive. Vugs are rare or absent in most of the quartz in the orebodies. Quartz bodies simulating the shape of drag-folds and bulbous forms are common.

A detailed study of the orebodies indicates that they are composite bodies of many elongated individual lenses of quartz concentrated in warped, dragged, and mashed areas at or near flexures and junctions of shear zones. In some orebodies the hanging-wall or foot-wall, and in others both walls of the orebodies, are marked by late slips that delineate the ore boundaries. In other orebodies the boundaries must be determined by assays.

In thin sections the early quartz exhibits features (Figure 2) common to most of the quartz lenses in the shear zones of the greenstone belt. In general, the quartz consists of a groundmass of medium-sized grains showing extreme undulous extinction and crowded with innumerable solid and liquid inclusions having planar and random orientations. The outline of these grains is irregular and many are bordered at some points by grains of secondary, clear, microcrystalline quartz.

The clear, microcrystalline quartz is a characteristic feature of the early quartz. It is not restricted in distribution to grain boundaries of medium-grained quartz but also pervades the grains as irregular diffuse patches, seams, and ramifying veinlets. Liquid inclusions are not present in most grains of the microcrystalline quartz and where present are too small to resolve under high magnification. Inclusions of sericite, carbonate, and rutile (?) may be as abundant as they are in the medium- to coarse-grained quartz. One characteristic of the fine-grained quartz is the sharp extinction of nearly all grains.

These two varieties of early quartz are found in all lenses in the Campbell system. In some the medium-grained variety predominates to make nearly 70 per cent of the quartz; in others the microcrystalline quartz is so abundant as to give the quartz a cherty appearance. In some places cherty quartz may be a fine-grained replacement of the schist, but in most occurrences it appears to be due to severe crushing and recrystallization of early medium-grained quartz. This origin is substantiated by the nearly

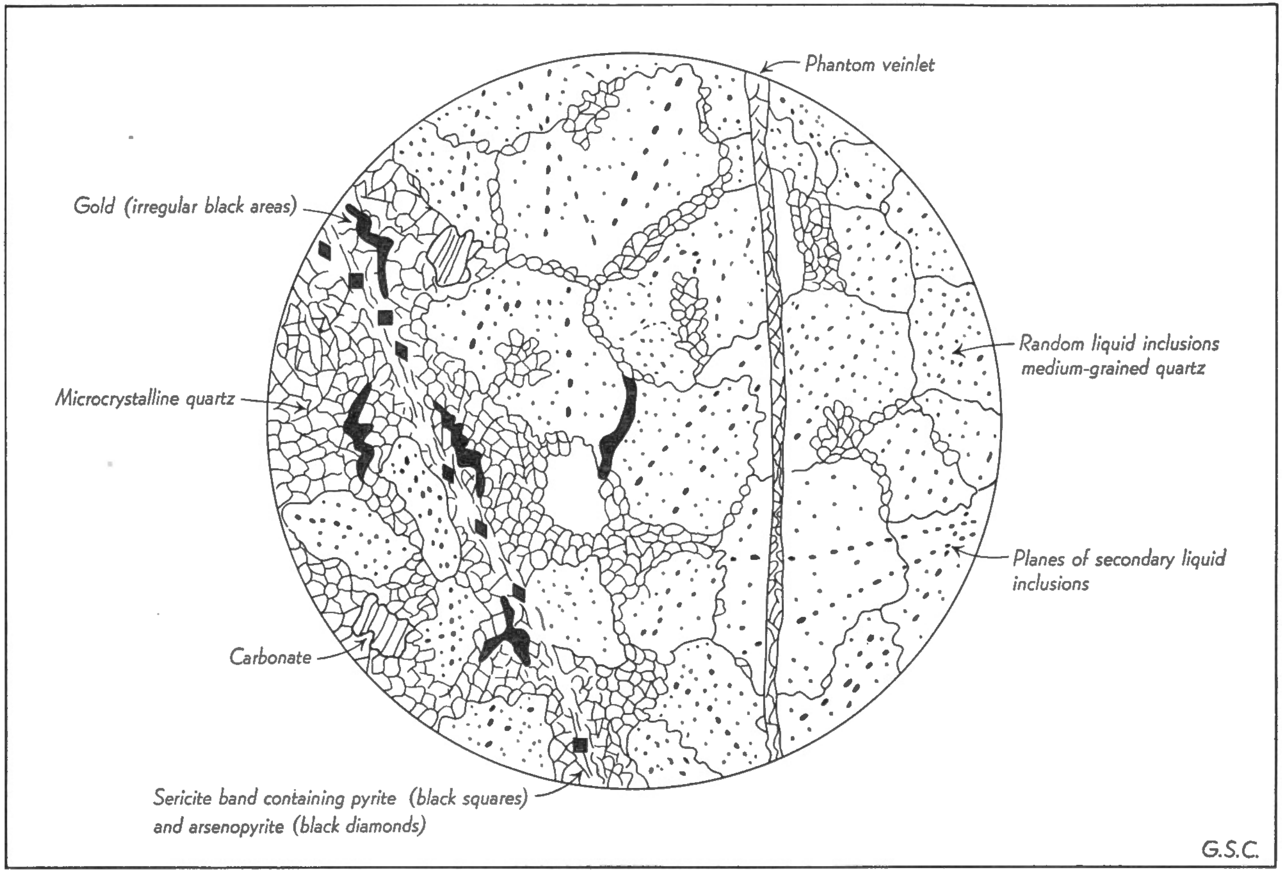

Figure 2. Diagrammatic sketch illustrating the microscopic features of gold-bearing quartz of the Yellowknife greenstone belt.

constant occurrence of the fine-grained quartz around grain boundaries of larger grains of quartz and by the fact that most patches and irregular seams of this quartz in the groundmass of medium-sized grains show no definite connections with veinlets or channel fractures. In some specimens, however, some clear quartz has been introduced as crosscutting phantom veinlets that contain small euhedral crystals of comb quartz with carbonate filling the spaces between the combs.

The inclusions in the early medium-grained variety of quartz are of two types, liquid and solid. Some liquid inclusions contain two phases, a liquid and a stationary or oscillating vacuole; others appear to contain only one phase, a gas, probably carbon dioxide, or have vacuoles too small to resolve under high magnification. The shape of the liquid inclusions varies from fairly well-developed negative crystals to irregular branching tubular cavities; the size lies in the range 0·002 to 0·01 mm. In the medium-grained variety of early quartz the liquid inclusions are distributed at random through the quartz grains and along planes that may be restricted to individual grains or may transect the boundaries of several grains. Beady lines of inclusions commonly mark grain boundaries and lamellæ in the quartz crystals. Most of the liquid inclusions, especially those that cut grain boundaries, appear to be secondary in origin; some of the randomly distributed inclusions may be primary and probably formed during the initial crystallization of the quartz.

Solid inclusions occur throughout the early quartz both in the medium-sized quartz grains and in the clear patches and irregular veinlets of microcrystalline quartz. Many are small and, therefore, difficult to determine. The larger ones are carbonate minerals and sericite, the smaller ones probably are minute specks of these minerals and acicular crystals of rutile or tourmaline. The inclusions of sericite and carbonate in some sections show a preferred orientation; in other sections the sericite shreds are randomly distributed. Some solid inclusions may represent unreplaced bits of the wall-rock, others may be micaceous minerals or carbonates deposited with the quartz.

The alteration zones adjacent to quartz lenses contain grains and small elongated lenses of quartz parallel with the foliation of the enclosing sericite and chlorite schist. The quartz in these occurrences is generally clear and contains few inclusions. Undulous extinction is extreme in some grains of this quartz; sharp extinction is present in other grains. Small veinlets of clear quartz that may contain carbonate, chlorite, sulphosalts, and gold commonly traverse the wall-rock alteration zones.

The late quartz of veins and lenses crosscutting the earlier quartz bodies and their bordering alteration zones is a coarse- to medium-grained, light flesh-coloured variety. In some places these veins and lenses are composed of intergrown euhedral to subhedral crystals of quartz and coarse-grained calcite deposited in vugs, fractures, crushed areas, and along the walls of the veins. In other places the quartz is finer grained, with a somewhat cherty appearance, and occurs in bulbous forms and irregular vein-like bodies.

In thin sections the late quartz is of two types, a medium- to coarse-grained variety with anomalous extinction and a fine-grained variety containing a few small inclusions and exhibiting sharp extinction. The grains of the medium- to coarse-grained variety are anhedral to subhedral in most occurrences and euhedral in vuggy parts of the stringers. All grains contain numerous inclusions of both the liquid and solid types. The anhedral grains exhibit marked undulous extinction and contain many inclusions and numerous patches, veinlets, and irregular areas of microcrystalline clear quartz. The euhedral grains contain only a few inclusions and a small amount of microcrystalline quartz, and do not exhibit the marked undulous extinction of the anhedral grains.

The liquid inclusions in both anhedral and euhedral grains of the late quartz occur randomly distributed, along discontinuous growth planes in the euhedral grains, and in planes crosscutting quartz grain boundaries. Two phase inclusions consisting of a vacuole and liquid are predominant. There appears to be little difference in size, shape, or contents between inclusions distributed at random, occurring along growth boundaries, or in secondary crosscutting planes. The degree of filling of the inclusions may be different, but without study on a heating-stage it is impossible to determine this.

The solid inclusions in the coarse, medium, and microcrystalline varieties of the late quartz consist of shreds of mica, blebs and patches of carbonate, and other fragments of minerals too small to resolve. The solid inclusions do not show preferred orientation and probably were deposited with the quartz.

NEGUS-RYCON SYSTEM

In the Negus-Rycon system the quartz occurs in lenses and veins seldom more than 5 feet in width and generally enclosed by narrow zones of carbonate-sericite schist. Quartz of two fairly distinct ages is present. The early quartz is black to grey and is cut and partly replaced by a later white quartz. In some lenses black and grey quartz is adjacent to the vein walls, and the white quartz occupies a medial position in the veins; in other veins the reverse is true. Many veins and lenses contain mottled quartz that contains small nuclei of black and grey quartz in a matrix of white quartz.

Some quartz lenses and veins are characterized by a development of subhedral quartz and small vugs filled with carbonate minerals and sulphosalts. In other lenses the quartz displays ribbon structures and carries highly altered fragments of schist. In these lenses the quartz commonly is crushed to give it a cherty appearance.

A study of thin sections of the early black and grey quartz reveals a groundmass of medium-sized anhedral to subhedral quartz grains intersected and surrounded by a ramifying system of veinlets and patches of microcrystalline quartz. Solid and liquid inclusions and irregular and wavy extinction abound in the medium-grained quartz, whereas the fine-grained variety is clear, contains very small liquid and solid inclusions, and possesses sharp extinction. Some thin sections show numerous phantom veinlets of clear, euhedral and subhedral quartz grains.

The solid and liquid inclusions in the black and grey quartz of the Negus-Rycon system exhibit the same shape and internal characteristics as those described for the Campbell system. In most thin sections, the inclusions are distributed randomly throughout the grains, in discontinuous trains, and along planes in the coarse- to medium-grained quartz. Most of the trains and planes of inclusions terminate at the quartz-grain boundaries, but a few traverse these boundaries and are secondary. Some planes of inclusions mark growth-boundaries in subhedral and euhedral crystals, but most euhedral crystals show a poor preservation of primary liquid inclusions. Solid inclusions consist of mica, chlorite, rutile (?), and other minerals too small to identify. These show both a random and oriented distribution. In the black and grey quartz, microscopic particles of carbon lying along wavy planes are responsible for the black and grey colour of the quartz (Boyle, 1953).

The late white quartz in the Negus-Rycon system shows different crosscutting relations to that of the Campbell system. The late white and early black and grey quartz are generally intimately intergrown, and crosscutting ladder-like stringers and veinlets of late quartz cutting both wall-rock alteration zones and early quartz such as are abundantly developed in the Campbell system are scarce. In some places, however, definite cutting relationships indicate two ages of quartz.

The late white quartz is generally coarse grained with some comb structures and vugs in the stringers. In thin sections it exhibits medium to coarse subhedral grains that contain some patches and veinlets of microcrystalline clear quartz. Phantom veinlets are common, and liquid and solid inclusions similar to those described for the early quartz are randomly distributed throughout the grains, along primary growth planes, at grain boundaries, and along secondary planes.

THE OCCURRENCE OF GOLD IN THE QUARTZ LENSES

The quartz lenses and veins in both systems contain pyrite, arsenopyrite, pyrrhotite, sphalerite, chalcopyrite, stannite, galena, stibnite, several sulphosalts of which tetrahedrite, jamesonite, and boulangerite are the most abundant, and aurostibite, gold, and scheelite. The alteration zones bordering the quartz bodies contain pyrite, arsenopyrite, and pyrrhotite, all of which may contain microscopic particles of gold.

Briefly, the observed paragenetic sequence of the metallic minerals in the schist and quartz bodies of the shear zones is as follows, with the oldest first.

(1) Pyrite, pyrrhotite, and arsenopyrite, and some gold. These occur in the alteration zones bordering and in unreplaced parts of schist within the early quartz lenses. In the alteration zones these minerals are early minerals except locally.

(2) Sulphosalts, gold, stibnite, stannite, sphalerite, pyrite, galena, and chalcopyrite. These minerals occur in vugs, fractures, phantom veinlets, and crushed areas in the early quartz lenses and veins and are always late minerals.

(3) Sulphosalts, sphalerite, galena, chalcopyrite, arsenopyrite, small amounts of pyrite, and gold. These commonly occur in vugs and crushed areas within late crosscutting quartz-carbonate veins and stringers.

The research in this bulletin is concerned with two main occurrences of gold, those in the early quartz lenses and their bordering alteration zones and those in the younger crosscutting quartz-carbonate veins and lenses. For a detailed description of all known occurrences of gold in the deposits the interested reader is referred to the author's unpublished description (Boyle, 1953) and Coleman's published account (Coleman, 1953).

In the alteration zones adjacent to early quartz veins and lenses pyrite and arsenopyrite contain gold in varying amounts as determined by assays and spectrographic analyses. This gold occurs as microscopic blebs in the pyrite and arsenopyrite, but it is possible that some gold may substitute for certain elements in the lattice of these minerals. It is probable that this gold was deposited with the enclosing pyrite and arsenopyrite. Native gold occurs as small plates, nuggets, and distorted crystals in the early medium- to coarse-grained quartz (Figure 2) along small fractures and highly crushed areas sealed with clear microcrystalline quartz. In these occurrences the gold is accompanied by granular arsenopyrite, stibnite, galena, sphalerite, and sulphosalts. Some gold may occur in the sulphosalts in a substitutional form.

The precise location of gold with respect to liquid inclusions and other features of the early quartz is fundamental to the interpretation of the decrepitation results. In most thin sections studied the plates, nuggets, and small distorted crystals of gold occur in the clear microcrystalline quartz areas that contain very few liquid and solid inclusions (Figure 2), and the relative age of the gold and liquid inclusions cannot be determined with certainty. In a few thin sections gold plates occurring in the microcrystalline quartz project into larger quartz grains, and planes of liquid inclusions that cut across quartz grain boundaries may occur along the projected strike of the protuberances of gold as shown in Figure 3. After considerable study of the relationships of the gold to the various features of the early quartz in both shear zone systems the following conclusions seem justified:

(1) Some gold is locked within the pyrite and arsenopyrite either in a finely divided state or substituting for certain elements in the sulphides.

(2) Native gold occurs in fractures, crushed areas, and small vuggy parts of the quartz. This mode of occurrence is constant and important, and this gold appears to have been deposited during a late stage of the mineralization process.

(3) In a few cases there appears to be some relationship between the distribution of liquid inclusions and gold, but whether the gold was deposited from the solutions trapped within the inclusions is not certain as the inclusions may have been formed earlier or

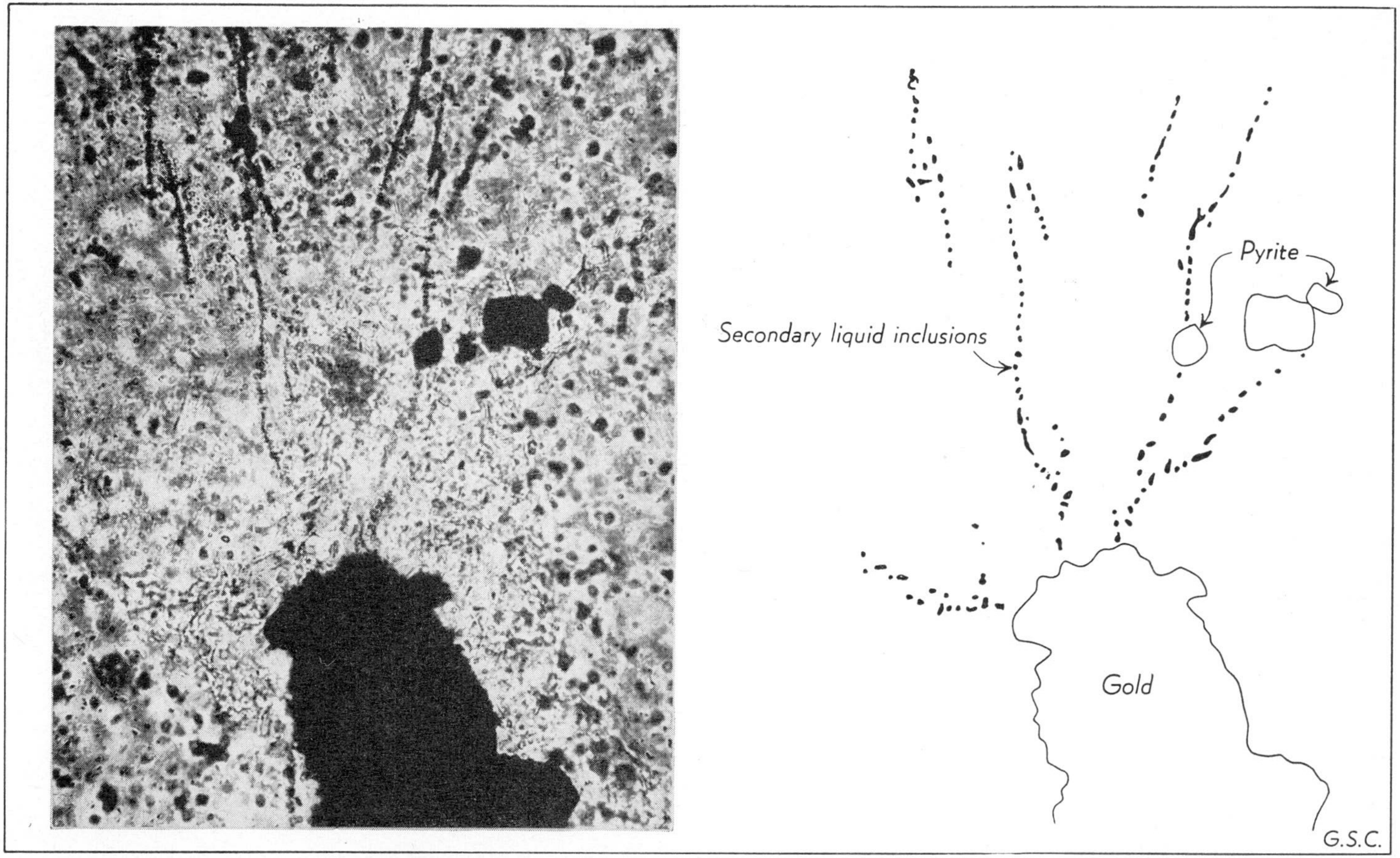

Figure 3. Photomicrograph and tracing of part of same showing secondary liquid inclusions localized in quartz along projected strike of a protuberance of a large nugget of gold, Con mine, Yellowknife. N.W.T. Transmitted light X 270.

later than the gold. The author's interpretation is that where the gold is along fractures now marked by planes of liquid inclusions the gold probably crystallized from the residual solutions trapped in the inclusions.

(4) The age of the gold in the microcrystalline quartz relative to the inclusions in this quartz cannot be determined with any certainty.

In the Campbell system small amounts of gold occur in calcite in the late crosscutting quartz-carbonate stringers and veins. This gold is accompanied by freibergite, bournonite and other sulphosalts, and chalcopyrite. In the Negus-Rycon system some gold occurs in small vugs and fractures in the late white quartz. In both these occurrences the gold appears to have been deposited at the same time as the quartz and carbonate.

DECREPITATION RESULTS AND CORRELATIONS

The decrepitation temperatures and intensities of the quartz in the two systems described are given in Figures 8B, 8C, 9B, and 9C. The variations of the average value of the decrepitation temperatures with depth are shown in Figures 4, 5, 6, and 7. To obtain the average value shown in Figures 4 to 7 the sum of all decrepitation temperatures on any one level was averaged. The following correlations are evident.

In the Negus part of the Campbell system the early quartz in the ore shoots is not characterized by either all high or all low decrepitation temperatures. There is a tendency, however, for higher temperatures (Figure 8B) to occur in the ore shoots, but the pattern is faint and not well developed. In general the high intensity readings in the early quartz (Figure 8B) can be correlated with low decrepitation temperatures and vice versa. The variation of the average decrepitation temperature with depth (Figure 4) shows that lower temperatures prevail at depth. The curve is only fair, however, and there are one or two average temperatures that fall wide of the mean position of the curve. The higher temperatures on the upper levels of the mine can be correlated with the largest and most productive part of the ore shoots.

The decrepitation temperatures of the late quartz in the Campbell system (Figure 8C) are generally higher in or immediately adjacent to the ore shoots. There is also a good correlation of high intensities with low decrepitation temperatures and vice versa (Figure 8C). The curve representing the variation of decrepitation temperature with depth (Figure 5) is consistent with the exception of one erratic value. Again the higher temperatures can be correlated with the largest and most productive parts of the ore shoots in the mine.

The decrepitation patterns in the Negus-Rycon system are complex. The higher decrepitation temperatures shown on the section of the N-3 and R-57 shear zones (Figure 9C) occur generally in ore shoots, but there are numerous exceptions. The correlation of decrepitation intensities with temperatures is not good (Figure 9C), but in a general way the higher the temperature the lower is the intensity and vice versa. There is a general decrease in the decrepitation temperature with depth, but the points do not fall on a single smooth curve (Figure 7). Instead, there appears to be two clusters through which two curves may be drawn.

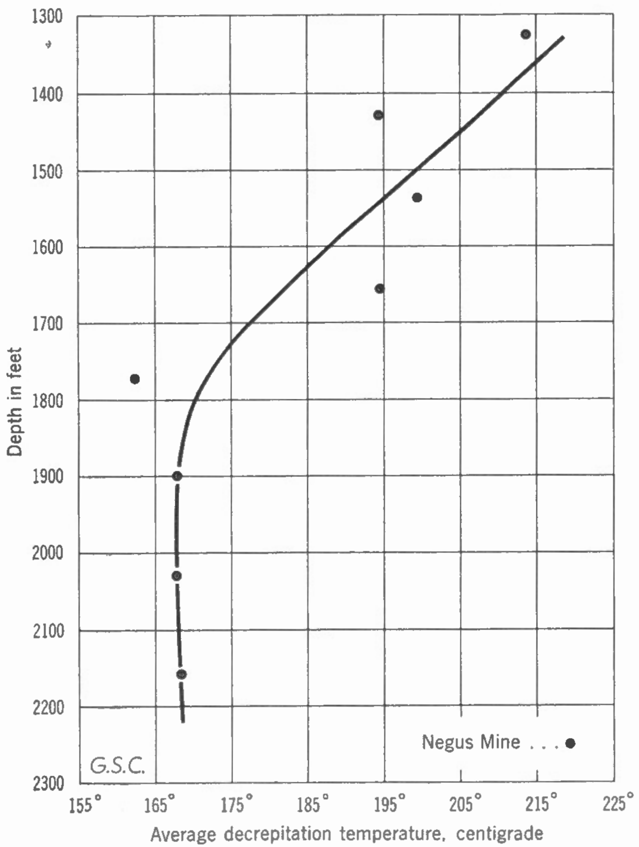

Figure 4. Graph showing variation of average decrepitation temperature per level with depth for early ore-bearing quartz, Campbell system, Negus mine.

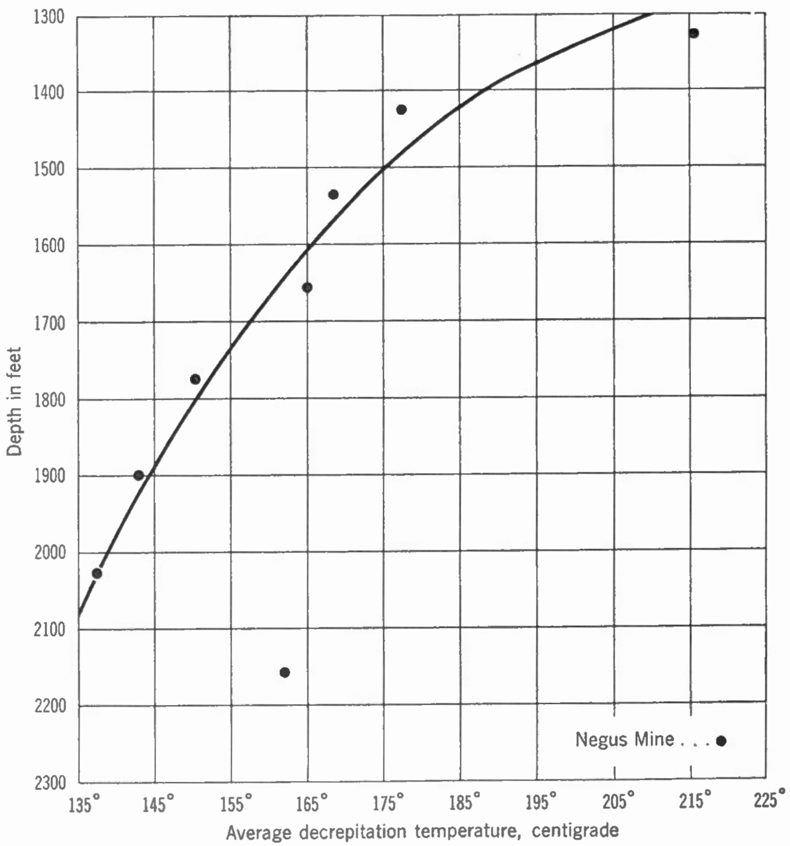

Figure 5. Graph showing variation of average decrepitation temperature per level with depth for late quartz, Campbell system, Negus mine.

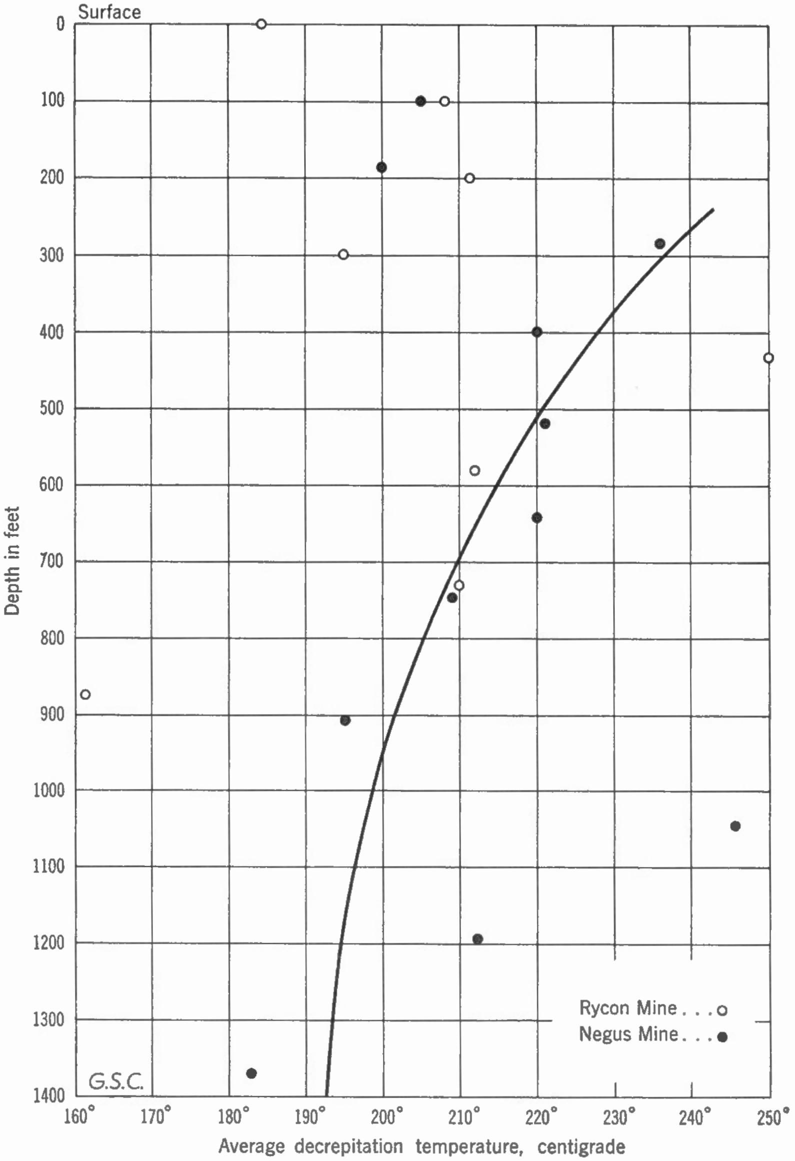

Figure 6. Graph showing variation of average decrepitation temperature per level with depth for early ore-bearing quartz, Negus-Rycon system, shear zones N-1, N-9, N-15, R-51.

In the N-1, N-9, N-15, and R-51 shear zones a similar complex pattern is present. Most of the high decrepitation temperatures occur in the ore shoots (Figure 9B), but there are exceptions. In most cases the intensity of decrepitation is greatest when the recorded decrepitation temperatures are low (Figure 9B), but the correlations are not good. Figure 6, illustrating the variation of average decrepitation temperatures with depth, shows that there is a wide spread in the values. There is, however, a cluster through which the mean curve exhibits a decrease of decrepitation temperature with depth.

In the Campbell system the early ore-bearing quartz containing a high proportion of clear microcrystalline quartz can be correlated with the higher decrepitation temperatures and lower decrepitation intensities. Thus, the cherty quartz consisting of nearly all microcrystalline clear quartz gives high temperatures (250 degrees +) and low intensities (1 or less), whereas the glassy coarse-grained quartz gives low temperatures (140 degrees range) and high intensities (3-4). The decrepitation temperatures and intensities also appear to vary with the toughness of the quartz. Thus, quartz that is brittle and easily crushed in a mortar usually records low temperatures and high intensities whereas the cherty tough variety records high decrepitation temperatures and low intensities. A correlation of the degree of crushing and recrystallization of the quartz and its toughness with decrepitation temperatures and intensities in the Campbell system are tabulated as follows:

CAMPBELL SYSTEM QUARTZ

Characteristics of quartz	Decrepitation temperatures	Decrepitation intensity
	Degrees	
Quartz exhibits a small amount of crushing and recrystallization, is coarse grained with an abundance of both secondary and primary liquid inclusions, and is brittle and easily crushed in a mortar	150 149 117 110 193	4 3 5 4 3
	Average 145	
Quartz is in part crushed and recrystallized with an abundance of fine-grained clear quartz about nuclei of medium-grained quartz containing both secondary and primary inclusions; quartz is moderately brittle to tough	135 210 165 149 190 240 212 156	3 3 3 4 3 2 3 3
	Average 182	

CAMPBELL SYSTEM QUARTZ—*Continued*

Characteristics of quartz	Decrepitation temperatures	Decrepitation intensity
	Degrees	
Microcrystalline quartz is abundant and widespread with only a few nuclei of medium-sized grains containing secondary and primary inclusions; quartz is tough	256	2
	214	3
	208	3
	191	1
	180	1
	Average 209	

In the Negus-Rycon system there is no marked correlation of decrepitation temperatures and intensities with the degree of crushing and recrystallization of the quartz as tabulated below. In this system most of the quartz is anhedral to subhedral and the occurrence of cherty quartz is not as abundant as in the Campbell system. The decrepitation temperatures and intensities appear to vary with the toughness of the quartz in the same manner as in the Campbell system.

NEGUS-RYCON SYSTEM QUARTZ

Characteristics of quartz	Decrepitation temperatures	Decrepitation intensity
	Degrees	
Quartz exhibits a small amount of crushing and recrystallization, is coarse grained and contains an abundance of primary and secondary inclusions; quartz is brittle and easy to crush in a mortar	131	3
	191	3
	150	4
	210	1
	183	1
	207	3
	188	1
	165	4
	191	3
	176	3
	Average 179	
Some fine-grained quartz with coarse grains containing abundant primary and secondary inclusions; quartz is moderately brittle, but some samples are tough and difficult to crush in a mortar	161	4
	194	2
	195	3
	Average 183	

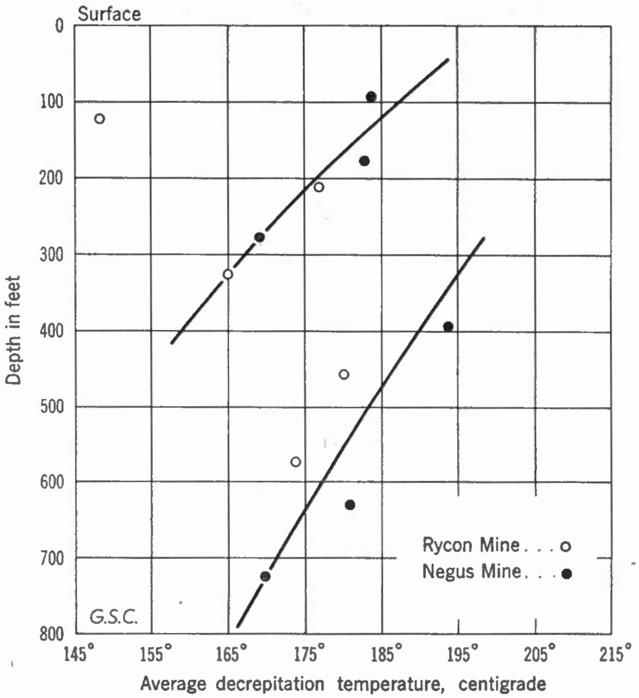

Figure 7. Graph showing variation of average decrepitation temperature per level with depth for early ore-bearing quartz, Negus-Rycon system, shear zones N-3 and R-57.

CONCLUSIONS

In summary and conclusion this study indicates:

(1) The quartz of the ore shoots is not characterized by consistently higher or lower decrepitation temperatures than that outside the ore shoots, although there is a tendency for higher decrepitation temperatures to occur in the ore shoots.

(2) The gold in the orebodies is markedly concentrated in the crushed and recrystallized quartz, and in this respect the zones of higher decrepitation temperatures and lower decrepitation intensities mark the ore shoots.

(3) In the Campbell system there is a decrease in decrepitation temperature in both early and late quartz with depth; however, this relationship is not pronounced in the Negus-Rycon system.

(4) The decrepitation temperature and intensity apparently are controlled to a large extent by the proportion of microcrystalline quartz to medium-grained quartz in the sample; thus the greater the proportion of microcrystalline quartz the higher the decrepitation temperature and the lower the decrepitation intensity.

Detailed petrographic study indicates that the microcrystalline quartz is probably developed by crushing and recrystallization of the medium-grained quartz. It seems logical that during the crushing and brecciation large numbers of liquid inclusions would be destroyed; at the same time it is possible that the tensile strength of the quartz would be increased in a similar manner to that of a metal that had been work hardened. The reduction in the number of liquid inclusions accounts for the decrease in decrepitation intensity and the probable increase in the tensile strength may produce the higher decrepitation temperatures. Thus, the variation of decrepitation temperatures and intensities is related to some extent to the amount of crushing and recrystallization that the quartz has undergone. The instrumental effect must be considered, however, when there are only a few liquid inclusions in the sample. In this case the slope of the decrepitation curve may be so low that the point of break is difficult to determine, in which case there is a tendency to select a decrepitation temperature higher than the true value.

(5) The significant decrease of the decrepitation temperature with depth of the early and late quartz in the Campbell system may be caused by decreasing crushing and recrystallization of the quartz at depth; that is, the control may be structural. On the other hand, the decrease in decrepitation temperature with depth may be explained by the temperature and pressure gradient existing at the time of formation of the secondary liquid inclusions. Petrographic and structural studies tend to substantiate the first of these conclusions.

To conclude, there are certain poorly developed patterns in the decrepitation results that may be significant in the analysis of the ore-forming process, but none appears to be clear cut enough to determine the direction of flow of mineralizing solutions or predict the possible location of ore shoots. The reason for the poorly developed patterns is the complexity introduced by extreme crushing and recrystallization of the quartz. In this respect the quartz in the Yellowknife orebodies is not suitable for decrepitation studies.

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