IMPORTANCE OF CLAY CHARACTERIZATION TO INTERPRETATION OF $^{40}Ar/^{39}Ar$ DATES ON ILLITE FROM CARLIN-TYPE GOLD DEPOSITS: INSIGHTS FROM JERRITT CANYON, NEVADA

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ABSTRACT

Illite has been dated extensively in attempts to determine the age of Carlin-type gold deposits. Theoretical considerations and empirical results from the Jerritt Canyon Mining District show that a number of problems must be addressed to properly interpret $^{40}Ar/^{39}Ar$ or K-Ar dates on illite from Carlin-type gold deposits. By characterizing, dating, and evaluating the illitic clays by various methods we were able to identify the ore stage illite and determine the degree and mechanism(s) of illite recrystallization. We question whether the temperature and duration of hydrothermal activity at the Carlin-type deposits was sufficient for complete loss of argon from illite by diffusion such that the isotopic clock of illite is completely reset. Most geochronologic studies of illite in Carlin-type deposits have not adequately addressed these concerns and therefore the age interpretations are suspect. Although using illite to date Carlin-type deposits is problematic, meaningful age constraints can be obtained if each of these concerns is carefully evaluated.

INTRODUCTION

The age of Carlin-type gold deposits is controversial because of the difficulty in finding datable minerals that are clearly cogenetic with ore formation. Of the possible minerals present in these deposits, clay minerals have been dated extensively in attempts to determine the age of these large gold deposits. Reported ages based on isotopic dates on white mica or sericite range from Middle Jurassic to Middle Tertiary (Wilson and Parry, 1995; Arehart and others, 1993; Groff and others, 1997; Drewes-Armitage and others, 1996; Hall and others, 1997). In contrast, crosscutting relationships between gold-bearing rocks and dated igneous rocks constrain the age of several deposits to the mid-Tertiary (Hofstra, 1994, Maher and others, 1993, Emsbo and others, 1996). The geochronology of clay minerals from the Carlin-type deposits is therefore an area of importance for understanding their genesis as well as of considerable interest for geochronologists.

Critical questions include: (**1**) Did the clay minerals form during gold mineralization?; and (**2**) Were the radiometric clocks of older clay minerals reset by the hydrothermal system? The Jerritt Canyon Mining District is an ideal place to evaluate the meaning of isotopic dates on clay minerals because gold mineralization is clearly younger than basalt dikes dated at 40.8 Ma (Hofstra, 1994). As part of our study to date gold mineralization at the Jerritt Canyon Mining District (fig. 1), we discovered that clay-size micas from high-grade-Au zones do not necessarily yield the age of mineralization. In fact, in the Jerritt Canyon Mining District the opposite is true. In the following sections, we discuss some of the reasons why careful characterization of clays for geochronology is essential for meaningful interpretations.

Using clays as geochronometers

The behavior of clay minerals and their use as geochronometers and geothermometers are topics of considerable research. Of particular importance to ore genesis studies are the evolutionary changes clay minerals undergo prior to, during, and subsequent to ore deposition. For sediment-hosted deposits, the clay cycle generally begins with weathering and transport of potassium-bearing minerals into a sedimentary basin. Upon burial in sedimentary basins, clay minerals undergo diagenesis and possibly isotopic resetting as temperature and depth increases. The chemical composition of pore fluids and amount of water-rock interaction between clay particles and fluids control changes in clay mineralogy. Complicating the evolutionary story, these sedimentary rocks may be altered by externally derived fluids such as **1**) fluids migrating along faults and fracture zones, **2**) fluids associated with igneous dikes and intrusions and **3**) metamorphic fluids. In any given setting, there are likely to be multiple generations of clays depending on the history of the rocks.

Dating hydrothermal ore deposits by K/Ar or $^{40}Ar/^{39}Ar$ methods requires that a potassium (K)-bearing mineral be identified that records the hydrothermal event of interest. In many cases, K-bearing clay minerals can be isolated from detrital micas and other K-bearing minerals by preparing samples of different grain sizes. However, separating different generations of the same clay mineral may be impossible. Therein lies the problem. K-bearing minerals from different origins will contribute their own isotopic histories to the total isotopic picture resulting in composite isotopic ages when multiple generations of clay minerals are analyzed as one sample.

Clay characterization is needed to determine what minerals are present, how they fit into the history of the rock, and what generation of clay should be dated. Therefore, careful sample handling is critical to insure that the clays do not suffer "investigator effects" (described by Clauer and others, 1992). Identification and separation (methods described by Moore and Reynolds, 1989) of the clays must be done using methods of disaggregartion that do not impose artificial grain sizes on minerals or alter the isotopic ratios of the minerals being analyzed.

Identification of minerals and polytypes as well as measurements of illite crystallinity are made by x-ray diffraction and SEM analyses. Illite crystallinity can be used as a qualitative indicator of temperature and degree of diagenetic evolution. For instance, Kisch (1990) defined low temperature metamorphic zones in terms of changes in crystallinity and temperature. Fundamental particle thicknesses are modeled by *Mudmaster* software, which, allows for evaluation and comparison of changes in the illite crystallinity. Changes in crystallinity inferred by changes in mean particle thicknesses also afford insight into possible illitization mechanisms and the inherited crystallinity of older mica in unaltered fractions. Thus, the crystallinity of illite provides a framework on which changes caused by the hydrothermal system can be measured.

Fine-grained clay samples are prone to argon loss during irradiation by the $^{40}Ar/^{39}Ar$ method. In order to capture $^{39}Ar_K$ released during irradiation the prepared clay samples are encapsulated into glass vials or "breakseals", which are sealed under high vacuum prior to irradiation (Foland and others, 1992). The loss of $^{39}Ar_K$ can significantly affect the calculated apparent and total-gas ages. The K/Ar method of dating is based on the natural decay of ^{40}Ar to stable ^{40}Ar by electron capture and positron emission (McDougall and Harrison, 1988). The $^{40}Ar/^{39}Ar$ method is based on the formation of ^{39}Ar by irradiation of ^{39}K with thermal and fast neutrons. Several critical assumptions are made about the samples including that the mineral systems have been closed to loss or gain of potassium, and that no radiogenic ^{40}Ar escaped from the mineral during its life. If these assumptions are violated then the radiometric ages are meaningless.

Early works by Hamilton and others (1989) and Burley and Flisch (1989) showed a trend of decreasing ages with decreasing grain size in samples collected from petroleum reservoirs. The mechanism responsible for the age difference was thought to be due to the diminishing presence of contaminants such as old, detrital mica in the finest size fractions. The finest fractions contained the purest fraction of diagenetic mica. Hunziker and others (1986) researching low grade metamorphic environments in the Glarus Alps, proposed that the K-Ar system of the less than 2 micron mica would be completely reset by diffusive loss of radiogenic argon at temperatures of about 260° C and duration of 10 million years. This model further predicts that even finer-grained micas could be reset at even lower temperatures. Yet, current studies of fine-grained mica suggest that argon loss by diffusion may not be significant in low-temperature metamorphic environments. Recently, Hassanipak and Wampler (1996) conducted experiments that showed that there was no preferential loss of radiogenic argon during step-heating in the finer grain sizes compared to the coarser grain sizes. Clauer and others (1997) found there was no notable diffusion from the cores of fine grained clays and that the decrease in isotopic ages associated with decreasing grain size of fine-grained illite particles is more commonly related to a decrease in the content of detrital contaminants than to diffusion. Because of the uncertainty associated with the degree to which clay minerals have undergone argon diffusion (ranging from none to complete diffusion), it is impossible to predict whether clay minerals from a particular deposit will record a mineralizing event or a composite date.

Clay minerals in Carlin-type deposits

Prior to gold mineralization, the sedimentary rocks that host the Carlin-type deposits contained a variety of K-silicate minerals such as detrital muscovite, K-feldspar, diagenetic illite, illite-smectite (I-S), or adularia (Mullens, 1980). Portions of many deposits (for example, Getchell and Gold Acres) are also hosted in Jurassic, Cretaceous, or Tertiary intrusive rocks or in their adjacent contact metamorphic rocks; each contains a variety of K-silicate minerals. The igneous intrusions and dikes are usually altered to some degree and commonly contain sericite and chlorite. Similarly, the contact metamorphic minerals are often altered to mica, chlorite, and a variety of clay minerals. K-metasomatism associated with many of these intrusions produced extensive areas of potassic or phyllic alteration unrelated to the Carlin-type hydrothermal system; examples included Getchell, Mike, and Bluestar/Genesis deposits. Some of the older K-silicate minerals provide opportunities for dating subsequent Carlin-type mineralization. For example, older K-feldspar and biotite are relatively unstable in Carlin-type fluids and are likely to be altered to clay minerals (Phinisey and others 1996). In contrast, older muscovite or illite are relatively stable and are less likely to be destroyed (Phinisey and others, 1996). The challenge then is to distinguish K-micas produced by the Carlin-type hydrothermal systems from older K-micas in the rocks. Alternatively, it is necessary to determine whether preexisting micas could have been completely reset via diffusive argon loss at the temperatures and duration of the hydrothermal system or by recrystallization. An additional problem in some districts is that the hydrothermal event associated with a Carlin-type system may be overprinted by a younger hydrothermal event. For example, mercury mineralization is present in the Miocene Carlin Formation that unconformably overlies the Meikle deposit (P. Emsbo, 1998 oral commun.).

The clay minerals associated with gold ores in the Carlin-type deposits have been described in only a few deposits, and seldom have clays been described from barren host rocks. Drews-Armitage and others (1996) describe the clay mineralogy in rocks of the Devonian calcareous Popovich Formation, the siliciclastic Rodeo Creek unit, and siliciclastic Vinini Formation, which host the Bluestar/Genesis deposits. In the distal portions of the deposit, kaolinite and cyrptocrystalline quartz replace the detrital quartz and feldspar in the Popovich Formation. In the most altered portions of the Popovich Formation proximal to the deposit, detrital minerals are replaced by kaolinite, quartz, and locally illite (mostly 1M). Altered siliciclastic rocks distal to the deposit contain quartz, kaolinite, and detrital illite (2M1). Altered siliciclastic rocks proximal to the deposit contain quartz, kaolinite, and detrital illite (2M1), with locally occurring quartz-illite (1M) veins. Bakken and others (1989) note that detrital feldspar at the Carlin deposit is present in minor amounts (up to a few percent) in unaltered Roberts Mountains Formation and is absent in altered rock. They also report an “abundance of smectite, illite, and kaolinite, and a trace of chlorite” in unaltered Roberts Mountains Formation. In altered Roberts Mountains Formation, the predominant clays are 1M and 2M illite with varying amounts of kaolinite. Smectite, chlorite, and feldspar were notably absent and detrital muscovite was present. Also at the Carlin deposit, Kuehn and Rose (1992) reported that barren Roberts Mountains Formation contains quartz, calcite, dolomite, K-feldspar, illite and pyrite which progressively changes to zones of quartz, kaolinite-dickite, and pyrite, but no feldspar, in the ore zone. They also determined that illite was destroyed at the expense of kaolinite-dickite formation in the ore zones. Ferdock and others (1997) suggest that illite formed during the early stages and was followed by kaolinite in the late stages of the gold mineralizing system at the Post-Betze deposit. In most of the deposits discussed above, there appears to be transitional zones of alteration mineralogy from the distal, barren host rocks to the fluid conduits and high-grade zones. However, not enough is known as to the effects a hydrothermal system may have played in resetting and (or) recrystallizing older illites, and thus changing their isotopic systems. More studies that characterize both the mineralogy and isotopic ages of barren and mineralized rocks are needed in order to determine what clays or generation of clays were formed by the gold system.

In summary, these studies suggest that: (**1**) The clay minerals formed by the hydrothermal fluids are dependent on the mineralogy of the host rock. (**2**) Illite, I-S (illite-smectite), and kaolinite are the main clay minerals produced by Carlin-type hydrothermal systems. (**3**) Older illite of multiple origins may be present in high-Au-grade ores. Even though illite and I-S can be dated by K/Ar and $^{40}Ar/^{39}Ar$ isotopic methods, their behavior under hydrothermal conditions of low temperature and short duration have not been well studied. Although any new illite that formed during gold deposition would record the age of mineralization, the effect on the isotopic systems of older illite is not well known. It is important to learn whether argon loss by diffusion from the crystal lattices occurs and whether these losses significantly affect the isotopic dates recorded by the illite.

CLAY MINERALS IN THE JERRITT CANYON MINING DISTRICT

Introduction

The results of clay studies on the Carlin-type gold deposits in the Jerritt Canyon Mining District illustrate many of the concerns mentioned above. The approach used herein was to consider the isotopic dates within the context of the geology of the district and environment of ore deposition. The geochemistry of unaltered barren rocks are compared to those of altered mineralized rocks to evaluate mass transfer, particularly with respect to K. The mineralogy and crystallinity of the clay minerals were also compared and modeled to improve interpretation of the isotopic dates.

Geology

The Jerritt Canyon Mining District is located in the Independence Mountains approximately 62 kilometers north-northwest of Elko, Nevada and approximately 50 kilometers north-northeast of the Carlin Trend (fig. 1). The district has produced approximately 4 million ounces of gold and has an estimated 4 million ounces of gold resources (Nevada Bureau of Mines and Geology, 1996). The mines are owned and operated by Independence Mining Company. The district includes several sediment-hosted disseminated gold deposits hosted by Lower Silurian to Lower Devonian Roberts Mountains and Upper Ordovician to Lower Silurian Hanson Creek Formations. These rocks are exposed through windows in the Roberts Mountains Allochthon. The deposits are highly irregular but generally tabular in morphology. Their distribution is controlled by intersections of favorable lithologies with a complex array of faults. Most gold is produced from relatively unweathered black, carbonaceous, pyritic, refractory ores, with lesser production from weathered, tan and buff, oxidized ore, and from jasperoid ores. The refractory ores are often decalcified and locally contain realgar in open spaces. Silicification to produce jasperoid, and decalcification and sulfidation to produce refractory ore are

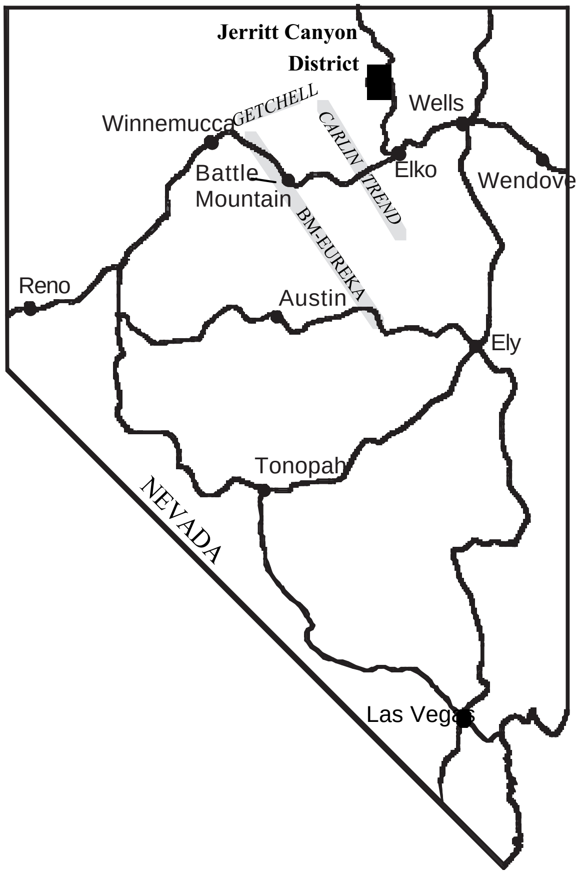

Figure 1. Location of the Jerritt Canyon Mining District in Elko County, Nevada. BM, Battle Mountain.

the major manifestations of the hydrothermal system that produced the gold deposits.

Environment of ore formation

Fluid inclusion data and mineral assemblages indicate that the hydrothermal fluids were not in excess of 260°C and generally much cooler. For example the presence of marcasite constrains the temperature to less than about 240°C (Murowchick, 1992). Fluid inclusion homogenization temperatures from quartz and calcite indicate trapping temperatures between about 120°C and 260°C (Hofstra, 1994). The duration of the hydrothermal system is unknown, but probably is in the range of 10,000 to 1 million years. It is also important to note that there are no Mesozoic intrusions exposed at the surface or in the mines in the mining district.

Mass Transfer

Geochemical analyses (Hofstra, 1994) of samples collected from high-Au-grade zones and distal unaltered rocks indicate a relative enrichment in the ores of Au, As, Sb, Hg, and Tl, and strong depletion of calcium and strontium, whereas aluminum, potassium, iron, and titanium were relatively immobile. An important consideration for growth and crystallization of new mica is the source of potassium and when it became mobile in the system. In the Jerritt Canyon Mining District, the potassium content of ores remained nearly constant, indicating K-metasomatism was not an important factor in generating the mica that is present in the deposits.

Clay characterization

Rock samples were collected from an altered and mineralized zone and from an unaltered zone approximately 20 meters apart within the same stratigraphic interval of the Roberts Mountains Formation. These rocks were separated into seven different grain-sizes fractions and analyzed by x-ray diffraction to evaluate the effects of the gold-bearing hydrothermal system on the mica (Hofstra, 1994, Folger and others, 1996). The size-fractions are 40-20, 20-5, 5-2, 2-1, 1-0.5, 0.5-0.1, and <0.1 µm, and the dominant clay mineral is 2M1 illite with lesser amounts of kaolinite present in both the altered and unaltered samples. Minor amounts of illite-smectite (I-S), having less than 30% expandability, were present in the altered 0.5-0.1 µm and the <0.1 µm size fractions, the two smallest fractions analyzed.

Crystallinity studies

Several new software programs developed specifically for clay minerals were utilized to evaluate changes in illite morphology. Eberl and others (1997) developed a method that eliminates the effect of swelling clays on peak measurements in x-ray diffraction data. By eliminating peak broadening effects of interlayered smectite as well as shifts in d-spacing, more accurate measurement of the particle thickness and mineral strain are permitted. Samples were sodium saturated and suspended in a solution of PVP-10 (polyvinylpyrrolidone having a molecular weight of 10,000), then mounted on polished silicon wafers. The software programs *Mudmaster* (Eberl and others, 1997), *Overgrowth!* (Eberl and others, 1997) and *Galoper* (Eberl and others, 1997) utilize this special x-ray diffraction data to measure and calculate the mean particle thicknesses.

Subtle changes in mica crystallinity were detected in similar grain-size fractions in unaltered and altered fractions. Mica crystallinity, measured by Kübler indices, decreases with decreasing grain size for both the altered and unaltered size fractions indicating that the altered samples have greater crystallinity when compared to their unaltered counterparts. The exception is the smallest grain-size fractions. Figure 2

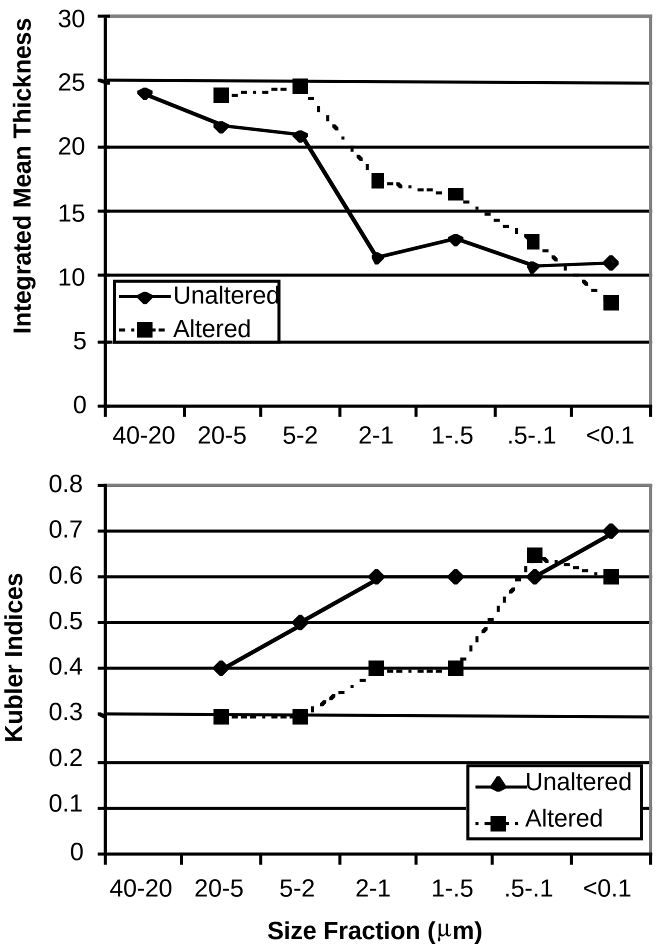

Figure 2. Comparison of crystallinity measured by the Kübler and integrated method peak methods.

shows a comparison of the Kübler indices measured from x-ray diffractograms and the integrated mean thickness calculated by *Mudmaster* for different grain size fractions. As the mica becomes more crystalline, the Kübler index (Kübler, 1964) decreases reflecting a sharper peak and a narrower peak width (°2θ). An increase in the integrated mean particle thickness is analogous to an increase in mica crystallinity. Only two coarse-grained fractions from the altered zone have crystallinities (Kübler index <0.37 °2θ) that fall within the anchizone (>200° C). All unaltered and the remaining fine-grained altered fractions had crystallinities (Kübler index > 0.37 °2θ) that fall within the diagenetic metamorphic zone (<200° C). This implies that the rocks were not heated to high temperatures during their depth burial history prior to mineralization and that the hydrothermal fluids were not very hot.

To measure the fundamental particle size distributions and mean particle sizes in altered and unaltered size-fractions *Mudmaster* was used. Samples were prepared using the PVP-10 method (discussed above) and analyzed by XRD. Integrated particle-size means were calculated from the particle-size distributions for each grain size fraction. The distribution curves for all size fractions are asymptotic rather than normal or log normal. Comparison of unaltered and altered mean values showed an increase in fundamental particle sizes in the altered size fractions. This reflects an increase in crystallinity for altered fractions similar to that observed by the Kübler method.

Galoper generated simulation of a distribution curve (fig. 3) that would resemble the original distribution curve of the unaltered fraction (green). Using an illitization mechanism of open system nucleation and growth, a distribution curve, which closely approximates the original unaltered fractions, was simulated (blue). The similarity between the original distribution curves and the simulated curve suggests that what we call "unaltered" mica formed by nucleation and growth processes. This simulated distribution curve was then used for further calculations using *Overgrowth!*. The resulting distribution curve remains asymptotic but with a greater proportion (frequency) of larger particle thicknesses.

Random ripening and Ostwald ripening (Eberl and others, 1997) are two possible illitization mechanisms for closed system growth. Here we mean the system was closed to potassium enrichment or depletion. When a particle is said to undergo a ripening process, one can imagine the addition of rims about a core particle.

If the original simulated particle size distribution undergoes random ripening, where the rate of crystal dissolution and growth is random with respect to specific surface area, then the particle distribution curve will remain asymptotic (orange line). If the original simulated particle size undergoes Ostwald ripening, then larger particles form at the expense of the smallest grain, and the original asymptotic curve takes on a log normal shape (brown line). Therefore, a random ripening model in which particles are randomly dissolved throughout the distribution and new particle material grow as overgrowths around rims of preexisting particles, most closely resemble the particle size distributions of the Jerritt Canyon samples. In this way the potassium is conserved, and the simulated particle size distribution increases only slightly mirroring a similar increase in illite crystallinity in the altered fraction. Assuming that the true age of the deposit is less than 40.8 Ma, just 15% of the illite present in the unaltered fraction would need to undergo random ripening to explain the changes in isotopic dates. This percentage works well for all grain sizes except the very smallest size fraction, where the presence of illite-smectite lowers the crystallinity and age even more.

K/Ar and $^{40}Ar/^{39}Ar$ dates

Age determinations were made of clay samples characterized by conventional K/Ar and step-heating $^{40}Ar/^{39}Ar$ methods. The diagram in figure 4 compares the total-gas ages (K/Ar and $^{40}Ar/^{39}Ar$) of the altered and unaltered size fractions.

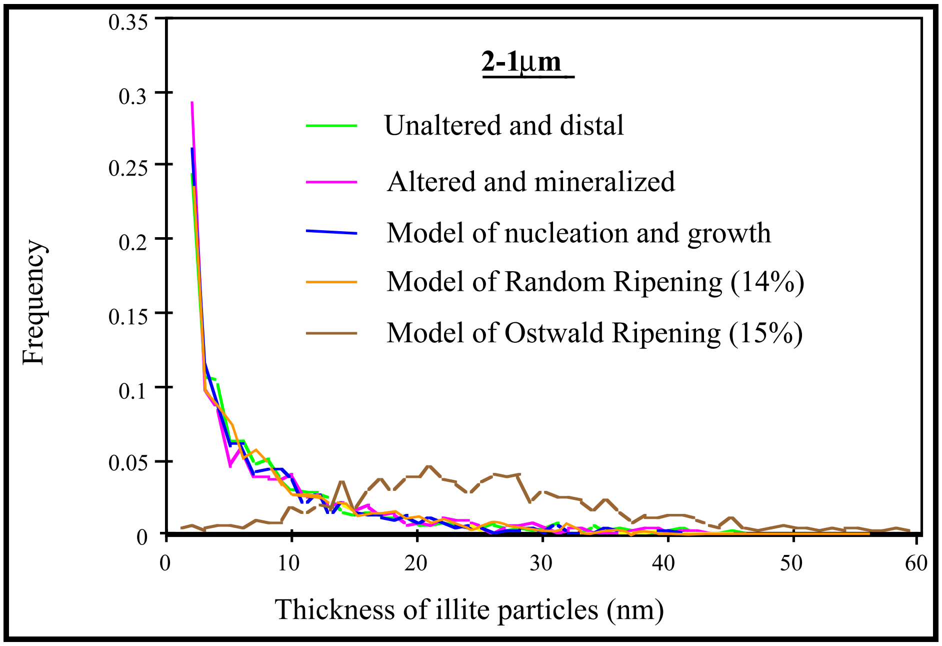

Figure 3. Original and simulated particle size distributions for the altered and unaltered mica. The green and magenta lines are the original particle size distributions curves for the unaltered and altered fractions respectively. In this fraction it can be seen that there is an increase in the frequency of the smallest particle sizes in the altered fraction as compared to unaltered. The blue line, representing the simulated model, nearly approximates these distribution curves.

The apparent age (y-axis) is plotted for each grain-size fraction (x-axis) where grain-size increases from right to left. What is striking and unexpected is that the altered fractions yield ages much older than the presumed <40 Ma age of the deposits. Also, the mineralized fractions have consistently younger ages than their unmineralized counterpart. This is seen in the nearly parallel downward shift in the trend of altered ages. The youngest total-gas age of 149 Ma was from the mineralized less than 0.1 micron size fraction.

The negative trend of total-gas ages for the size fractions could be a reflection of the evolution of mica through a random ripening process, a result of mixing of several different generations of illite within the sample, or both. The altered fractions have younger ages and greater crystallinity (smaller Kübler indices and larger particle thickness) compared to their unaltered counterparts. It can be seen that the effect of the hydrothermal system on the mica has been an almost uniform lowering of total-gas ages across all grain sizes except in the finest fraction (<0.1mm) which has been lowered even more significantly.

$^{40}Ar/^{39}Ar$ spectra of the altered and unaltered grain-size fractions show trends of decreasing apparent ages with decreasing grain-size (fig. 5). Several features are evident from the $^{40}Ar/^{39}Ar$ age spectra of samples.

First, the percentage of argon loss due to $^{39}Ar_K$ recoil is progressively greater in the smallest size fractions. This phenomenon is related to the effective grain size and crystallinity of the sample; the finer grained and less crystalline a sample, the greater the amount of ^{39}Ar lost during irradiation. This process is relatively unimportant in the coarse grained samples such as the 40-20 mm fractions, but is quite significant in the finer size fractions. Because $^{39}Ar_K$ is present in the "breakseal" volumes and radiogenic ^{40}Ar is absent, the $^{39}Ar_K$ was recoiled during irradiation. This process effectively increases the $^{40}Ar/^{39}Ar$ ratio of the samples for some or all of the additional heating steps. Thus the apparent age, which is directly proportional to the $^{40}Ar/^{39}Ar$ ratio, is too high for some or all heating steps of the samples that exhibit $^{39}Ar_K$ recoil. In contrast, the total-gas date, which is analogous to a conventional K/Ar date, is calculated for each sample by adding the recoiled ^{39}Ar and non-recoiled ^{39}Ar; thus a true measurement of the $^{39}Ar_K$ is used. Figure 6 compares the amount of $^{39}Ar_K$ recoil and crystallinity for both the altered and unaltered fractions.

Second, the altered and fine-grained fractions have strongly discordant and broader step-like spectra, indicating a more complex geologic history compared to unaltered and coarse-grained fractions (fig. 5). In the past there have been two widely accepted explanations for this type of spectral shift: a partial loss of radiogenic ^{40}Ar by volume diffusion due to a

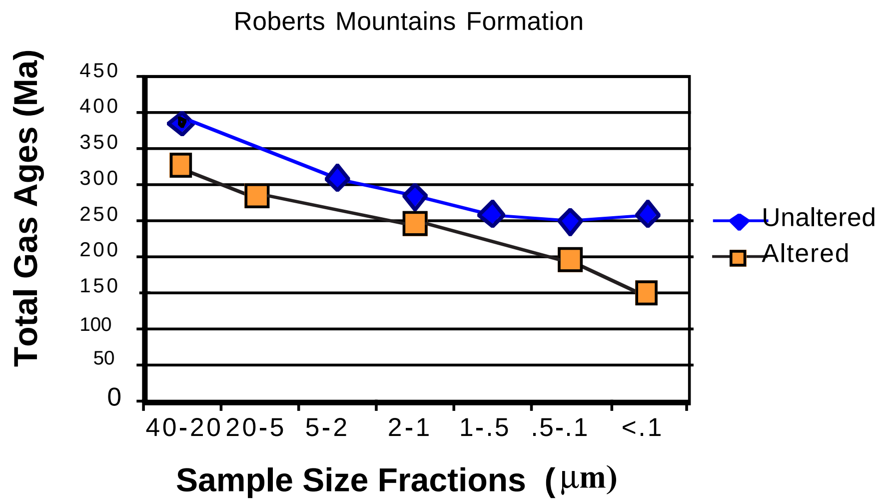

Figure 4. Comparison of total-gas ages for K/Ar and $^{40}Ar/^{39}Ar$ analysis of mica from the Roberts Mountains Formation. Isotopic ages for the altered and unaltered fractions are listed in table 1

thermal event or a mixing of different populations of mica with different argon retention characteristics. A convincing argument can be made that the changes in isotopic dates result from the addition of new illitic material as overgrowth formed by a ripening process or as very fine-grained illite-smectite formed by a later event such as the gold stage. These deductions are supported by the recent findings by Clauer and other researchers (discussed above) that show fine-grained illite is argon-retentive at temperatures similar to those at Jerritt Canyon and to the observed changes in illite crystallinity and morphology at Jerritt Canyon identified in XRD and SEM analysis and modeled by *Mudmaster*, *Galoper*, *and Overgrowth!*.

Discussion of Jerritt Canyon

The isotopic dates obtained from unaltered and altered size fractions represent composite ages because they are derived from samples having multiple populations of mica. The altered samples generally have lower ages and higher crystallinity than their unaltered counterparts. The smaller size fractions are less crystalline than the coarser sizes reflecting a population of less thermally mature mica in the smaller fractions. Yet the inverse relation of increased crystallinity and decreased apparent ages suggest that the hydrothermal system did have an effect on the crystallinity of the mica and also the total-gas ages. An illitization mechanism

Table 1. Total-gas ages, Kübler indices, integrated-mean thickness (IMT), and percentage of recoiled $^{39}Ar_K$ for each size fraction of the altered and unaltered samples.

Sample	Size	Ages	Kübler	IMT	39 Recoil
Unaltered	40-20	384.4		24.1	0
(J9054)	20-5		0.4	21.5	
	5-2	307.5	0.5	20.8	15.9
	2-1	282.4	0.6	11.4	
	1-.5	258.6	0.6	12.9	
	.5-.1	248.2	0.6	10.7	19.7
	<0.1	257.4	0.7	11	22.3
Altered	40-20	324.5			0
(J9051)	20-5	283.7	0.3	24	
	5-2		0.3	24.7	8.3
	2-1	245.8	0.4	17.4	
	1-.5		0.4	16.3	20.3
	.5-.1	195.3	0.65	12.8	
	<0.1	149.1	0.6	8.1	28.2

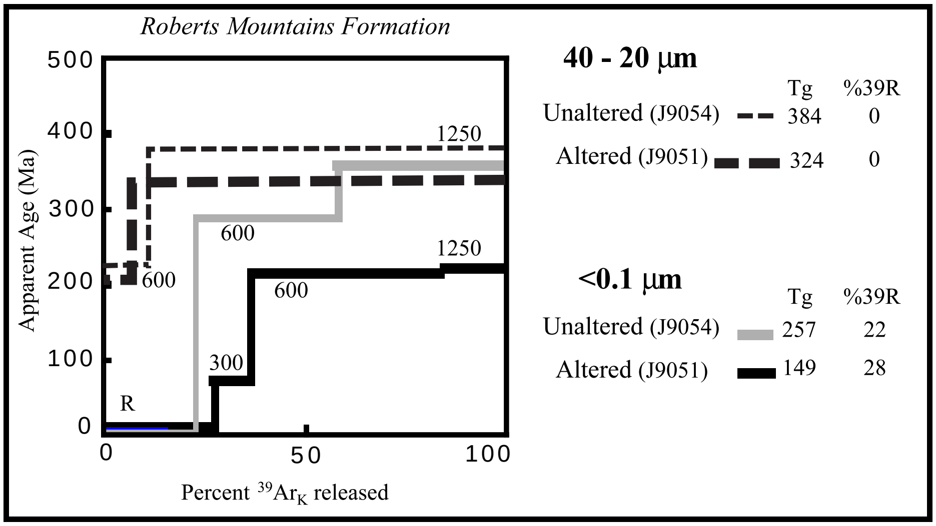

Figure 5. The argon spectra of altered and unaltered size-fractions from the Roberts Mountains samples. The amount of $^{39}Ar_K$ (potassium-derived argon) recoil has been included with the entire $^{39}Ar_K$ released and is designated by the letter "R". Also listed is the grain-size fraction analyzed (size) and the total-gas dates (Tg).

of random ripening best describes the changes seen in particle size distributions as well as the isotopic dates. This process incorporates new material as overgrowths on the older cores, thereby lowering the composite ages. Even though the greatest concentration of newly formed hydrothermal illite is found in the smallest size fraction, the effects of the older mica present in the sample is still reflected in the surprisingly old dates. The neoformation and random ripening of illite appear to explain changes observed in the isotopic ages and illite morphology.

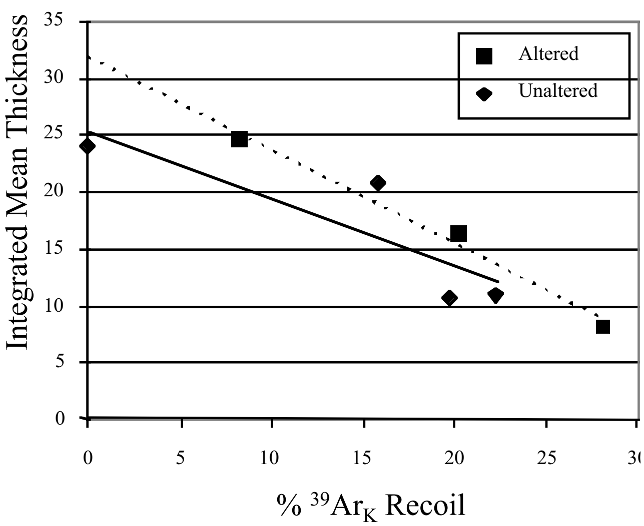

Figure 6. Integrated mean thicknesses calculated by *Mudmaster* reflect a trend similar to the Kübler Index where the less crystalline mica is more prone to argon recoil

CONCLUSIONS

The concerns described above and the empirical results from the Jerritt Canyon Mining District demonstrate that a number of problems must be addressed to properly interpret isotopic dates on illite from Carlin-type gold deposits. Most important to address are: **1**. Identification of the mineralogical changes in the host rocks due solely to the mineralizing event. To do this requires comparative studies of both barren and mineralized rock. **2**. Demonstrate that the mica being dated is ore stage and not contaminated by earlier generations of mica. This can be quite difficult if the mica has undergone ripening or partial dissolution. **3**. Alternatively, prove that the temperature and duration of mineralization was sufficient for argon loss by diffusion to completely reset the isotopic clock of the micas. **4**. The samples analyzed must be prepared and dated in a manner so as not to deleteriously influence the isotopic results.

Previous geochronologic studies of illite in Carlin-type deposits have not adequately addressed these concerns and therefore the age interpretations are suspect. Although using micas to date Carlin-type deposits can be problematic, meaningful results can be obtained if these concerns are addressed. With appropriate care, samples can be selected to increase the likelihood of finding ore stage micas that will yield the age of mineralization. This is the direction of our current research.

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