

**Validation and representation of fluid inclusion microthermometric data using the fluid inclusion  
assemblage (FIA) concept**

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## **Abstract**

This paper discusses the principles of the fluid inclusion assemblage (FIA) method and its application in validation and representation of fluid inclusion microthermometric data. An FIA is a group of fluid inclusions that were entrapped at the same time, and the contemporaneity of the fluid inclusions within an FIA is based on petrographic relationships rather than on their similarity in microthermometric attributes. If an FIA can be identified based on petrography, then the consistency of microthermometric data within the FIA indicates that the fluid inclusions entrapped a homogeneous fluid and have not been significantly modified since the entrapment; the microthermometric data are valid, and only the mean value of the fluid inclusions within the FIA should be used for data compilation. Conversely, if fluid inclusions within an FIA show variable microthermometric attributes, then the inclusions may have either entrapped two or more phases of fluids and in variable proportions (heterogeneous trapping), or may have been significantly modified after entrapment (e.g., necking down or stretching); the microthermometric data are invalid, and should not be used in data compilation. In many cases, the contemporaneity of a group of fluid inclusions cannot be determined, and so the FIA approach cannot be strictly applied. However, the FIA concept is still useful even in such cases. If fluid inclusions closely associated with each other show similar microthermometric data, it is a positive sign that the inclusions have entrapped a homogeneous fluid and have not been significantly altered after entrapment. Microthermometric data of individual fluid inclusions should be used in data compilation, but caution should be paid not to concentrate data collection in a limited area. On the other hand, large variation of microthermometric data within a small area in a crystal may indicate heterogeneous trapping, post-entrapment modification, or superimposition of more than one generation of fluid inclusions. A detailed mapping of fluid inclusion microthermometric data and comparison with better defined FIAs can be used to discriminate these possibilities.

**Keywords:**

Fluid inclusion assemblage, FIA, microthermometry

## **1 Introduction**

The validity of fluid inclusion analyses relies on three basic assumptions, or the Roedder's rules (Bodnar, 2003a and b): 1) the inclusions trapped a single, homogeneous phase, 2) the volume of the inclusions has not changed since entrapment (isochoric system), and 3) the composition of the inclusions remains unchanged (Roedder, 1984). In most fluid inclusion studies, especially those prior to the 1990's, these assumptions were commonly regarded true without rigorous examination. Indeed, it is not an easy task to prove if the volume or composition of a fluid inclusion has changed since its entrapment, because we do not know the initial volume and composition of the inclusion in the first place. The concept of fluid inclusion assemblage (FIA), proposed by Goldstein and Reynolds (1994), provides a way to verify the above assumptions through some simple petrographic and microthermometric work. This paper summarizes the principles of the FIA method, mainly based on the work of Goldstein and Reynolds (1994) and Goldstein (2003) and shows how this method can be applied to validate microthermometric data and how the data should be represented. Further more, it is proposed that even when an FIA cannot be strictly established, which is more common than exceptional, the FIA concept can still be used to put constraints on the validity of fluid inclusion data. Detailed procedures of treating the microthermometric data in such cases are discussed.

## **2 Fluid inclusion assemblages and principles of microthermometric data validation**

A fluid inclusion assemblage (FIA) is defined as “the most finely discriminated, petrographically associated group of inclusions” or “groups of inclusions that can be defined, by petrographic means, as the most finely discriminated events of fluid inclusion entrapment” (Goldstein and Reynolds, 1994). Each FIA is defined based on a petrographic association in which all inclusion vacuoles represent the finest temporal resolution possible as to timing of initial closure of the inclusion vacuoles (Goldstein, 2003). Two key points in this definition are 1) an FIA is petrographically distinguishable, and 2) all inclusions in an FIA are synchronous. A further implication of the FIA

definition is that all inclusions in an FIA trapped a fluid of approximately the same composition at approximately the same temperature and pressure (Bodnar, 2003a), in the case of a homogeneous parent fluid. The best examples of fluid inclusion assemblages are secondary inclusions in a single healed microfracture, often called fluid inclusion plane or FIP, and primary inclusions in a single, most finely discernible and petrographically distinguishable growth zone (Goldstein and Reynolds, 1994). A term similar to FIA, called “group of synchronous inclusions” or GSI, was introduced by Fonarev et al. (1998). This term was preferred by some because it emphasizes the importance of timing in fluid inclusion entrapment (Touret, 2001).

The application of the FIA concept in assessing fluid inclusion data is based on the following reasoning: if the inclusions within an FIA trapped a single, homogeneous phase and the volume and composition of the inclusions have not changed since entrapment, then the fluid inclusions should have the same composition, density, and homogenization temperatures. Thus, if the microthermometric attributes of the fluid inclusions within an FIA are consistent, it can be inferred that the assumption of homogeneous trapping and isochoric system is correct, and the microthermometric data are valid. Conversely, if the microthermometric attributes of the fluid inclusions within an FIA are variable, the data are invalid, and the cause may be one of the following (Fig. 1): 1) two immiscible fluid phases were present and were entrapped in individual inclusions (heterogeneous trapping) in variable proportions (Fig. 1A), 2) some of the inclusions were further divided into smaller inclusions after certain phase changes (necking down) (Fig. 1B), and 3) the fluid inclusions were modified (stretched or partly opened) to variable degrees (Fig. 1C). While heterogeneous trapping itself provides useful information about the fluid system (co-existence of two immiscible fluid phases, e.g., a boiling system), the homogenization temperatures are higher than the trapping temperature. Necking down can result in homogenization temperatures both higher and lower than the initial trapping temperature, whereas stretching generally increases the homogenization temperature.

If the fluid inclusions within an FIA trapped a single, homogeneous fluid (Fig. 1C), it may be argued that these inclusions should have the same homogenization temperatures even if they were stretched, because they experienced the same geological history and should have been stretched to the same degree. However, it has been shown that fluid inclusions of different sizes and shapes are subject to different degrees of modification under a given condition. In general, the larger the inclusion, the less pressure is required to reequilibrate the inclusion (Bodnar, 2003b), and irregular inclusions are more prone to modification than regularly-shaped inclusions. Therefore, the consistency of homogenization temperatures of fluid inclusions with different sizes and shapes within an FIA can be used to indicate that the inclusions have not been significantly reequilibrated.

Ideally all the fluid inclusions within an FIA should have identical homogenization temperatures if they were not modified after entrapment. In practice, a certain range of homogenization temperatures should be tolerated. According to Goldstein and Reynolds (1994), if 90% of the variation of homogenization temperatures of fluid inclusions with different size and shapes in an FIA are within 10 - 15°C, the FIA can be considered to have consistent homogenization temperatures, and the fluid inclusion microthermometric data are valid.

### **3 Recognition of fluid inclusion assemblages and data representation**

From the definition of fluid inclusion assemblages it is clear that the most important criterion for a group of fluid inclusions to be treated as an FIA is that they were entrapped at the same time. This contemporaneity of entrapment must be supported by petrographic evidence rather than by similarity in microthermometric data. For example, if two fluid inclusions occur near each other and have very similar homogenization temperatures, they do not necessarily constitute an FIA unless there is petrographic evidence indicating they were entrapped at the same time. Conversely, since an FIA is established based on petrographic evidence, the inconsistency of microthermometric data within the

FIA, such as illustrated by the variable vapor/liquid ratios in Figure 1 cannot be used as an argument against the correctness of the FIA.

Fluid inclusions occurring along a healed microfracture, or a fluid inclusion plane (FIP), can be relatively easily recognized as an FIA (Fig. 2A). Complications may arise when microfractures of different orientation are densely developed and crosscut each other, so that at the intersections it is difficult to ascertain to which FIP a given fluid inclusion belongs. However, it is generally possible to find FIPs without such complication in a given sample.

Inclusions distributed along a growth zone in a crystal can be generally treated as an FIA (Fig. 3A). However, cautions should be exercised if the growth zone is relatively wide or if the crystal is overprinted by secondary and pseudo-secondary inclusions. For wide growth zones, fluid inclusions cannot be lumped into one FIA, but must be further divided into more finely discriminated FIAs. The scanning electron microscope – cathodoluminescence (SEM-CL) method, which can reveal fine growth zones which are not visible in transmitted light, is particularly useful in distinguishing FIAs, especially for quartz (Van den Kerkhof and Hein, 2001; Goldstein, 2003). In many cases, the growth zones are reflected by the change in color rather than by the continuous distribution of fluid inclusions, and the fluid inclusions only occur in a segment of the growth zone (Fig. 3B). These inclusions may be considered as an FIA if they are parallel to the growth zone and there is no other complication.

Once a fluid inclusion assemblage is established and the fluid inclusions are measured for microthermometry, the microthermometric data should be validated according to the criteria described in the previous section. If the microthermometric data are consistent within the FIA (e.g., homogenization temperature variation with a range of 10 - 15°C), then they are valid. Note for CO<sub>2</sub> homogenization temperatures, a much narrower range is required, generally within a few degrees. All the microthermometric data should be recorded, but only the mean value should be used in statistics (e.g., in calculating the mean value of a sample or in constructing histograms or correlation diagrams),

otherwise the dataset will be skewed or biased toward certain FIAs that contain a large number of fluid inclusions, all of which have similar microthermometric attributes. For example, although a total of 42 carbonic inclusions were measured for homogenization temperatures in four microfractures in a quartz crystal shown in Fig. 2, only the mean value of each microfracture should be included in statistics. Histograms of individual microfractures may be used to illustrate the distribution of microthermometric data within individual FIAs, as shown in Fig. 2C (1-4), but microthermometric data of individual fluid inclusions should not be included in a histogram summarizing the data for the whole sample, otherwise the importance of homogenization temperatures in the range from 0 to 2°C and from 4 to 7°C would be exaggerated.

For presentation of microthermometric data in spreadsheets, it is recommended that both the ranges and the mean values of individual FIAs be listed (e.g., cases 1-4 and 9-11 in Table 1), the former indicating the consistency of the data within individual FIAs, and the latter to be used in compilation or statistics of data for a whole sample or a mineral phase studied.

Generally it is relatively easy to measure the homogenization temperatures than various melting temperatures (e.g., ice-melting temperatures). While all fluid inclusions within an FIA should be measured for homogenization temperatures to evaluate consistency, the melting temperatures need not be measured for all the inclusions in order to save time. Therefore, for a given FIA, the number of measurements of melting temperatures is generally less than that of the homogenization temperatures (e.g., cases 9-11 in Table 1).

If all fluid inclusions in an FIA are liquid-only aqueous inclusions (e.g., Fig. 3A), they indicate homogeneous trapping and no significant post-trapping modification. The absence of a vapor bubble is a result of metastability, and generally indicates relatively low trapping temperatures (Roedder, 1984). Homogenization temperatures may be measured if a bubble can be induced by putting the sample into a freezer for several days without artificially stretching the host mineral (which can be detected if



significantly different homogenization temperatures are obtained). In many cases, a bubble cannot nucleate even after cooling for many weeks, and therefore homogenization temperatures cannot be obtained. However, the ice-melting temperatures can still be measured after artificially stretching the inclusions (by overheating to 200°C or more) to nucleate a bubble. For data presentation, “L-only” may be put in the homogenization temperature column of the spreadsheet (e.g., cases 15-17 in Table 1).

For FIAs that yield inconsistent microthermometric data, if necking down or stretching is interpreted to be the cause, then generally the data are invalidated and should not be used in statistics. If the variation of microthermometric data is caused by heterogeneous trapping (e.g., evidenced by co-existence of vapor-rich and liquid-rich end members) and convergence toward the two end members is demonstrated, the microthermometric data of the two end members can be considered valid, but those in between should be discarded. For examples, both oil and gas inclusions are present in the same microfracture shown in Fig. 4, which indicates co-existence of two immiscible phases (oil and gas) during the entrapment of the inclusions. Although some oil inclusions show variable vapor/liquid ratios and are likely the result of heterogeneous trapping, most oil inclusions have very similar vapor/liquid ratios and their homogenization temperatures fall in a narrow range from 65 to 70°C. These homogenization temperatures are valid and their mean value represent the trapping temperature of the oil in the microfracture.

A special case of inconsistent microthermometric data is the co-existence of mono-phase (liquid-only) and biphasic (liquid + vapor) fluid inclusions, commonly found in calcite cements formed in shallow environments. Either stretching or heterogeneous trapping (e.g., the trapping of air and water in the vadose zone) can be responsible for the presence of the bubble. In such cases, the homogenization temperatures of the biphasic inclusions are useless, although ice-melting temperatures may be measured for the biphasic inclusions and compared to those of the liquid-only inclusions measured with the artificial stretching method described above. In the spreadsheet, the range of

homogenization temperatures can be recorded, but the “mean” value should be “L-only” rather than the mean value of the biphasic inclusions (cases 18-19 in Table 1).

#### **4 Non-FIA occurrences and data representation**

In many situations, rather common than exceptional, the contemporaneity of a group of fluid inclusions cannot be petrographically determined. In such cases the FIA approach cannot be strictly applied, and the variation of microthermometric data beyond that expected for homogeneously trapped non-modified FIAs (e.g., 10 - 15°C for homogenization temperatures of aqueous inclusions) should not be held as evidence against the validity of the data. On the other hand, the FIA concept can still be used to put constraints on the data, because neighboring fluid inclusions, even if not entrapped at the same time, should not normally show very large differences in microthermometric attributes. If such large difference is observed, possibilities of necking, heterogeneous trapping, stretching, and superimposition of more than one generation of fluid inclusions should be examined. The interpretation and representation of microthermometric data of the most common non-FIA occurrences of fluid inclusions are discussed below.

##### ***4.1 Isolated fluid inclusions***

Isolated fluid inclusions occur alone or far away from other inclusions in a mineral crystal (Fig. 5). This kind of fluid inclusions are liked by fluid inclusionists because they are most likely primary, besides those distributed along growth zones. However, these inclusions are also the most difficult to validate for their microthermometric data. From the definition of fluid inclusion assemblages it is clear that an FIA contains more than one fluid inclusion, and therefore isolated fluid inclusions cannot be treated as fluid inclusions assemblages. A general caution that may be taken about isolated fluid inclusions is that if the homogenization temperature of a given inclusion is exceptionally high,

constituting an obvious outlier, it is likely that the inclusion has been subject to some kind of post-trapping modification or has been the result of heterogeneous trapping, and such possibilities should be further examined in the same sample or in other samples from the same area. If there is no evidence against the validity of the microthermometric data, individual fluid inclusions should be listed in the spreadsheet (cases 12-14 in Table 1) and included in data compilation or statistics.

#### ***4.2 Randomly distributed fluid inclusions***

Randomly distributed fluid inclusions may have been entrapped during the crystallization of a mineral (primary inclusions), or controlled by multiple, irregular, and densely spaced fractures (secondary inclusions). The second situation may be distinguished from the first one by the presence of some fluid inclusions obviously controlled by microfractures merging into those randomly distributed. In either case, the fluid inclusions, which typically inundate the crystal (e.g., Fig. 2A, area 5), cannot be lumped into an FIA. In these cases it is generally difficult to define an FIA objectively, but fluid inclusions within a small area in the crystal may be treated loosely like an FIA: large variation of microthermometric attributes within a small area warns the possibility of violation of the Roedder's rules. Conversely, moderate variation of the data, such as shown in Fig. 2B, cannot be used as evidence to reject the data. A more rigorous but more time-consuming approach is to map the microthermometric measurements on the crystal to see if there is any systematic spatial variation, which may be related to crystal growth. Unless there is evidence indicating heterogeneous trapping or post-trapping modification, the microthermometric data of individual fluid inclusions, rather than the average of a group, should be listed in the spreadsheet (cases 6-8 in Table 1) and used in data compilation or statistics. However, it should be avoided to collect too many data from a limited area, which may lead to a skewed dataset.

#### ***4.3 Scattered fluid inclusions***

In many cases fluid inclusions are randomly scattered in a crystals (Fig. 6) without any visible pattern in relation to growth zones or microfractures. They are similar to the randomly distributed fluid inclusions described above except the density of distribution is lower. The principle of validation and presentation of the microthermometric data is the same as for randomly distributed fluid inclusions (cases 20-21). For example, the similarity of homogenization temperatures of fluid inclusions in barite shown in Fig. 6A suggest that the microthermometric data are possibly reliable, despite the fact that barite is relatively soft and known to be prone to post-trapping modification of fluid inclusions. The small variation of homogenization temperatures of scattered fluid inclusions in sphalerite shown in Fig. 6B also indicates the validity of the data.

#### ***4.4 Clusters of fluid inclusions***

A cluster of fluid inclusions contain a limited number of inclusions within a limited area that is separated by inclusion-free areas from other fluid inclusions in a crystal (Fig. 7). Like isolated inclusions, fluid inclusions in a cluster are likely primary, although they may also be pseudosecondary or even secondary. Unlike isolated fluid inclusions, however, the microthermometric data may be validated to some extent. If the inclusions in a cluster are of primary origin, they probably do not belong to an FIA in a strict sense. If the inclusions are of pseudosecondary or secondary origin, i.e., controlled by a microfracture (which is not straight and unobvious) or by intersection of microfractures, they satisfy the definition of an FIA. In either case, if microthermometric data are fairly consistent (e.g., Fig. 7), they are considered as valid. If microthermometric data are significantly variable within the cluster, heterogeneous trapping or post-trapping changes are suspected and the data are possibly invalid. With regard to data presentation, if the variation is small and/or the inclusions are interpreted as pseudosecondary or secondary (e.g., Fig. 7B), it is recommended that the range and mean of the cluster be listed as for FIAs (cases 22-23), whereas if the inclusions are interpreted to be primary (e.g., Fig. 7A), individual inclusions are to be listed (cases 24-26).

The occurrence of fluid inclusions in clusters can also constrain the interpretation of liquid-only inclusions. If all the inclusions in a cluster are liquid-only (e.g., Fig. 8A), it is likely that these inclusions were entrapped at relatively low temperature conditions and have not been stretched. If the liquid-inclusions co-exist with biphasic inclusions with variable vapor/liquid ratios, as shown in Fig. 8B, it is possible that there were two phases during the entrapment of the inclusions, such as in a vadose environment.

## **5 Discussion and summary**

Before the development of the FIA concept, fluid inclusions were generally treated as statistical populations. A common practice was to divide the fluid inclusions into primary and secondary ones for a given host mineral or mineral deposit, and lump all the microthermometric results for primary inclusions into one category and secondary inclusions into another one. The data were typically presented in histograms, where each individual fluid inclusion was treated as a data entry. The problem with such treatment of data is twofold: firstly, the validity of the data is difficult to assess, and secondly, the data set may be skewed toward certain populations where large amounts of measurement were made.

It is not uncommon to see fluid inclusion data being reported as, for example, homogenization temperatures ranging from 80 to 400°C. Since there are no constraints on the validity of the data from the FIA approach, it is difficult to determine if the large variation of homogenization temperatures truly reflects the range of temperature during the mineral formation, or if some of the inclusions have been stretched or necked. It is also common to see statements such as “the two peaks in the histogram of homogenization temperatures suggest that there were two episodes of hydrothermal activities during the formation of the mineral deposit”. Such statements may not be valid because the two peaks may merely be caused by, for example, numerous fluid inclusions being measured from a few growth zones.

With the FIA approach, the validity of data is assessed during data collection rather than during data compilation: if it is found that the microthermometric data within an FIA are not consistent, the data set is rejected for compilation or statistics (e.g., histograms). On the other hand, if microthermometric data within an FIA are consistent, it is the mean value of the whole FIA rather than the value of each individual inclusion that should be compiled and input for statistics. Thus, if 10 FIAs were studied, and 10 fluid inclusions were measured in each FIA, the number of data entries for statistics should be 10 rather than 100. This treatment of data may lead to an underestimation of the amount of work involved, but it truly reflects the distribution of data.

Once an FIA is defined and the homogenization temperatures are found to be inconsistent, the various possibilities should be examined: necking, stretching, and heterogeneous trapping. However, another possibility should not be forgotten: the FIA may not have been identified correctly or finely enough in the first place. Generally fluid inclusions that are isolated, scattered, randomly distributed, and in clusters should not be treated strictly as FIAs. Thus moderate variation in microthermometric attributes may not be used as a reason to reject the data. On the other hand, very large difference in microthermometric data between neighboring inclusions signifies that the inclusions may have been modified or resulted from heterogeneous trapping, and the data may not be valid, or that the inclusions are of different generations (primary versus secondary).

The fluid inclusion assemblage concept can play an important role in solving some major geological problems. For example, it has been found that some world-class orogenic gold deposits (the Ashanti gold belt in Ghana and the Campbell-Red Lake deposit in Canada) are characterized by the predominance of carbonic fluid inclusions (Schmidt Mumm et al., 1997; Chi et al., 2006a). The nature of the carbonic inclusions was not well understood, and it was suspected that these inclusions resulted from preferential leakage of water from initial aqueous-carbonic inclusions (Bakker and Jansen, 1994). Detailed fluid inclusions studies indicate that the homogenization temperatures of the carbonic fluid inclusions within individual FIAs are fairly consistent, and carbonic inclusions have not been observed

to co-exist with aqueous-carbonic inclusions with variable carbonic/aqueous ratios, as would have been expected if the carbonic inclusions resulted from alteration of aqueous-carbonic inclusions. Therefore, the carbonic inclusions are interpreted to be a true record of a carbonic fluid which may be responsible for gold mineralization (Chi et al., 2006a).

In other cases, the application of the FIA method serves to invalidate microthermometric data, which may otherwise lead to wrong conclusions. A fluid inclusion study of the oil sands in the eastern margin of the Western Canada Sedimentary Basin, the largest oil sands accumulation in the world, was initiated with an aim to evaluate the thermal conditions of biodegradation of the oil (Chi et al., 2006b). It has been generally agreed that oil sands result from biodegradation of oils in conventional oil reservoirs. Hydrocarbon biodegradation used to be thought of as an aerobic process related to flushing by meteoric water, but anaerobic processes, although relatively slow, are now believed to be the main cause (Head et al., 2003). Such biodegradation is related to bacteria which can survive in temperatures up to about 80°C, above which the reservoir rocks are pasteurized and biodegradation of hydrocarbons may be prevented (Head et al., 2003). Preliminary studies of the oil sand samples indicate that the homogenization temperatures of oil inclusions are extremely variable and are mostly above 80°C (Chi et al., 2006b). If the results were assumed to be valid without examination, it would have been inferred that the oil was much hotter than the reservoir or that the bacteria could survive at temperatures much higher than 80°C. Using the FIA concept, however, it was suggested that most of the oil inclusions have been modified after entrapment (poor sealing of the oil inclusions) or have resulted from heterogeneous trapping, and so the homogenization temperatures are mostly invalid (Chi et al., 2006b). This example illustrates the importance of the FIA method, without which correct conclusions cannot be made from fluid inclusion data in certain circumstances.

In summary, the fluid inclusion assemblage method is a practical method that can be used to determine if the basic assumptions about fluid inclusion system (i.e., homogeneous trapping and

isochoric and isocompositional system) are valid. In addition to validating microthermometric data, the FIA method can avoid bias in the collection and presentation of fluid inclusion data. An FIA is a group of inclusions that were entrapped at the same time, and the contemporaneousness of entrapment must be petrographically demonstrated (e.g., growth zones or healed microfractures). If the microthermometric data within an FIA are consistent and fall within a certain range, the data are valid, and the mean value of all the inclusions is used to represent the FIA and used in data compilation and statistics. If the microthermometric data within an FIA are divergent, the data are generally invalid and should not be used. In cases where an FIA cannot be established (e.g., fluid inclusions that are isolated, scattered, randomly distributed, and in clusters), the criteria of data validation cannot be applied as strictly as for FIA, but very large difference in microthermometric data between neighboring inclusions should be regarded as indication that the inclusions may have been subject to significant post-trapping modification or have resulted from heterogeneous trapping, or that they represent different generations of inclusions.

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## Captions of tables and figures

Table 1. Representation of microthermometric data for FIAs and non-FIA fluid inclusions

Figure 1. Three common causes of microthermometric inconsistency (as reflected by variable vapor / liquid ratios) for fluid inclusions in an FIA: heterogeneous trapping (A), necking down (B), and stretching (C).

Figure 2. A) Photomicrograph showing several FIAs of carbonic fluid inclusions in healed microfractures (labeled 1-4) in a quartz crystal and randomly distributed fluid inclusions (area 5). B) homogenization temperatures of carbonic fluid inclusions randomly distributed in area 5 outlined in A. Note most inclusions are too small to be measured and are not shown here for clarity. C) Histograms of homogenization temperatures of carbonic fluid inclusions from microfractures 1-4 and area 5 shown in A. Note the narrow range of homogenization temperatures within individual healed fractures and the relatively wide range for the randomly distributed ones.

Figure 3. A) Fluid inclusions distributed along growth zones in dolomite crystals. All the inclusions in the growth zone pointed by the arrows are liquid-only. B) Fluid inclusions in a growth zone in a sphalerite crystal. Note the small range of homogenization temperatures indicated by the numbers beside the inclusions.

Figure 4. Oil and gas inclusions co-existing in a microfracture in calcite. Note the gas inclusions do not contain oil, and most oil inclusions show similar vapor/liquid ratios and their homogenization temperatures fall in a small range (65 to 70°C), indicating homogeneous trapping of oil and gas

separately. Some oil inclusions show relatively large vapor/liquid ratios and are the results of heterogeneous trapping.

Figure 5. Isolated fluid inclusions (pointed by arrows) in sphalerite (A) and fluorite (B).

Figure 6. Scattered fluid inclusions in barite (A) and sphalerite. Note the small ranges of homogenization temperatures indicated by the numbers beside the inclusions.

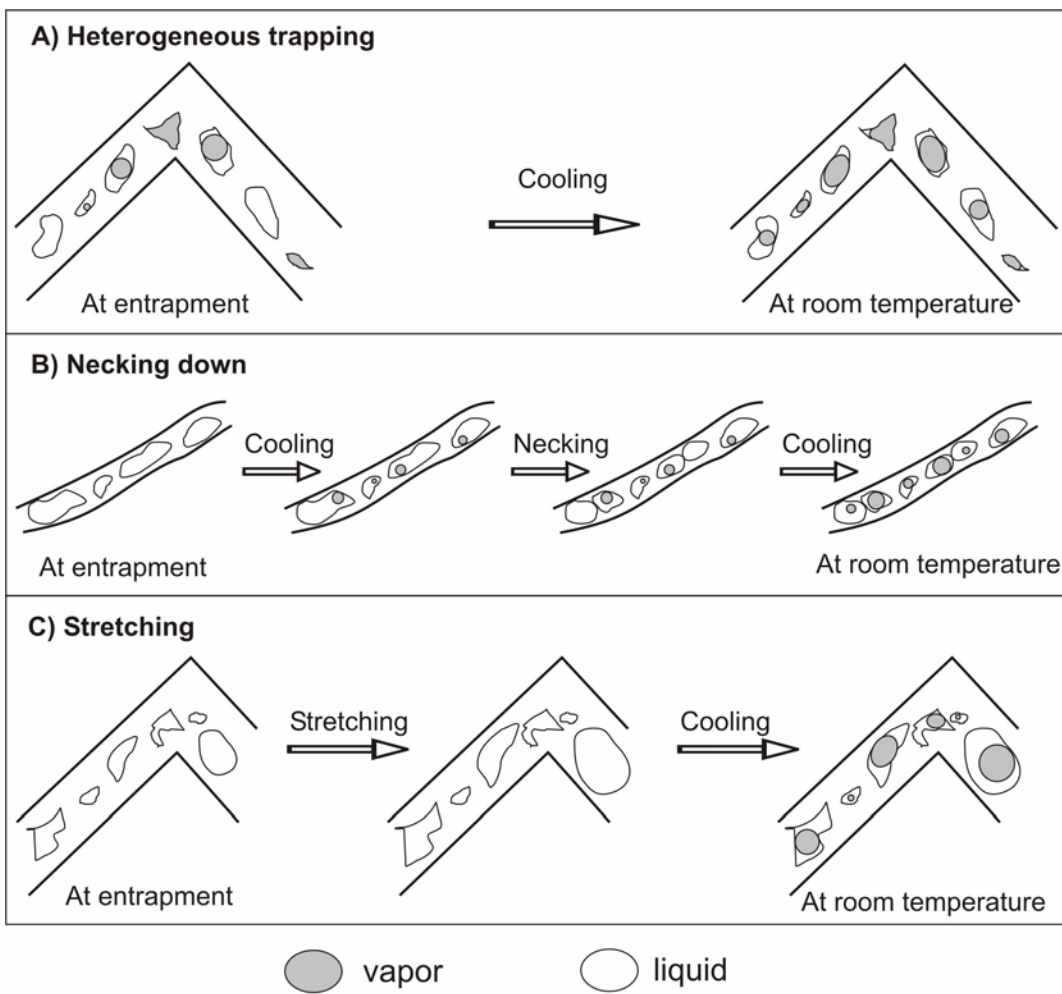
Figure 7. Clusters of fluid inclusions in calcite showing small ranges of homogenization temperatures indicated the numbers beside the inclusions. The inclusions in A are probably primary, and those in B are likely pseudosecondary inclusions controlled by a short microfracture.

Figure 8. A) A cluster of liquid-only inclusions in barite. B) A cluster of fluid inclusions with variable vapor/liquid ratios including liquid-only inclusions.

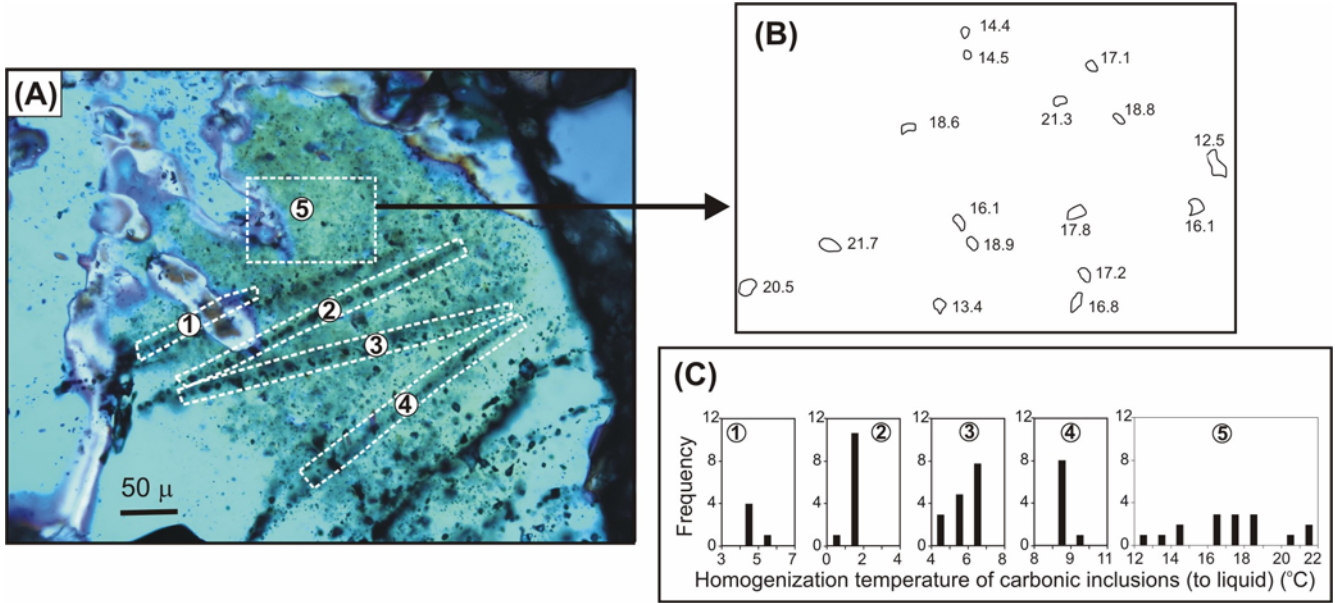
**Table 1. Representation of microthermometric data for FIAs and non-FIA fluid inclusions**

Sample number	Host mineral	Occur.*	Size (µm)	V/T** (%)	T <sub>mH<sub>2</sub>O</sub> (°C)		Th <sub>CO<sub>2</sub></sub> (°C)		Th (°C)		Case #
					Range	Mean (n)	Range	Mean (n)	Range	Mean (n)	
GC002	Quartz	HF	2~7	100	-	-	4.6~5.0 L	4.8 (5)	-	-	1
		HF	2~8	100	-	-	0.6~1.7 L	1.6 (12)	-	-	2
		HF	2~8	100	-	-	4.0~6.5 L	5.7 (16)	-	-	3
		HF	2~9	100	-	-	8.7~9.2 L	8.8 (9)	-	-	4
		RD	5	100	-	-	16.8 L	16.8	-	-	5
			4	100	-	-	17.2 L	17.2	-	-	6
			6	100	-	-	16.1 L	16.1	-	-	7
			9	100	-	-	12.5 L	12.5	-	-	8
GC050	Fluorite	GZ	5~12	8~10	-15.3 ~ -13.8	-14.5 (3)	-	-	125.7~138.9 L	133.2 (7)	9
		GZ	3~9	10	-14.9 ~ -14.2	-14.6 (2)	-	-	133.7~144.5 L	135.7 (5)	10
		GZ	4~15	10~12	-17.1 ~ -16.8	-17.0 (2)	-	-	150.3~159.8 L	155.8 (6)	11
		I	9	15	-20.1	-20.1	-	-	166.4 L	166.4	12
		I	3	10	-16.8	-16.8	-	-	153.5 L	153.5	13
		I	6	10	-17.2	-17.2	-	-	140.5 L	140.5	14
GC078	Barite	HF	4~18	0	-0.3 ~ -0.1	-0.2 (2)	-	-	L-only	L-only (5)	15
		HF	6~15	0	-0.4 ~ -0.2	-0.3 (1)	-	-	L-only	L-only (8)	16
		HF	5~20	0	-0.3 ~ 0.0	-0.2 (3)	-	-	L-only	L-only (6)	17
		HF	4~16	0~60	-0.3 ~ -0.1	-0.2 (3)	-	-	L-only ~ >250	L-only (4)	18
		HF	7~15	0~20	-0.5 ~ -0.2	-0.3 (3)	-	-	L-only ~ 235.3	L-only (5)	19
		S	9	5	-8.4	-8.4	-	-	97.0 L	97.0	20
GC123	Calcite		15	5	-7.8	-7.8	-	-	99.0 L	99.0	21
		C	3~8	5~8	-3.3 ~ -3.7	-3.5 (2)	-	-	85.1~93.2 L	88.7 (3)	22
		C	4~11	5~8	-2.9 ~ -3.0	-3.0 (2)	-	-	91.2~93.7 L	92.1 (4)	23
		C	5	5	-11.2	-11.2	-	-	108.1 L	108.1	24
			7	5	-12.1	-12.1	-	-	119.2 L	119.2	25
	6	5	-11.9	-11.9	-	-	110.6 L	110.6	26		

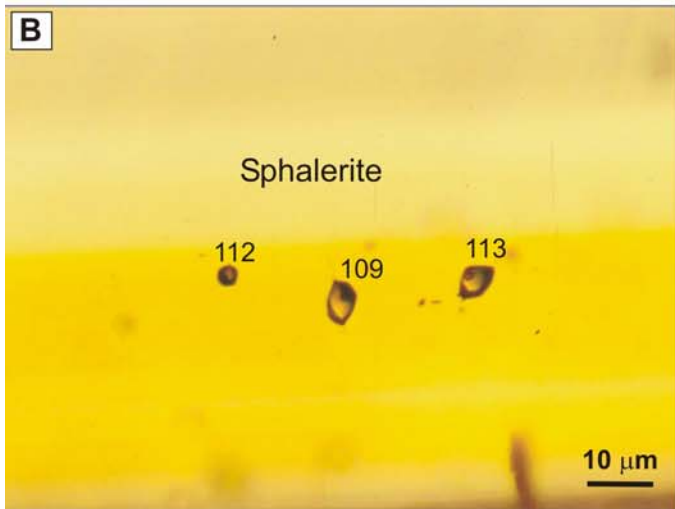
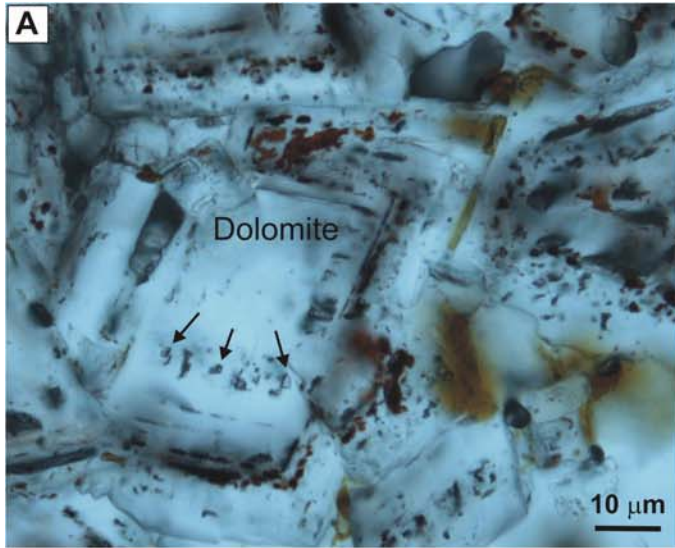
\* Occur. = mode of occurrences; HF = healed fracture; RD = randomly distributed; GZ = growth zone; I = isolated; C = cluster; S = scattered. HF and GZ are FIAs, and the others are non-FIAs. \*\* V/T = vapour / total ratio. In the homogenization columns, L = homogenization to liquid, and V = homogenization to vapor. In the mean columns, the number in the parentheses is the number of inclusions measured.



Chi and Lu, Fig. 1

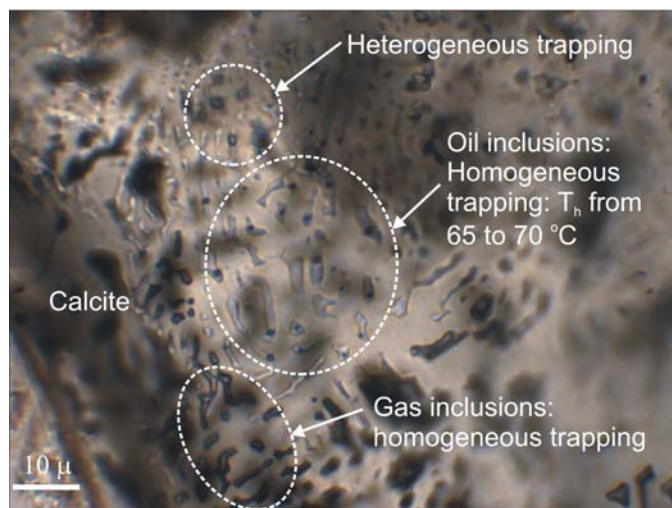


Chi and Lu, Fig. 2

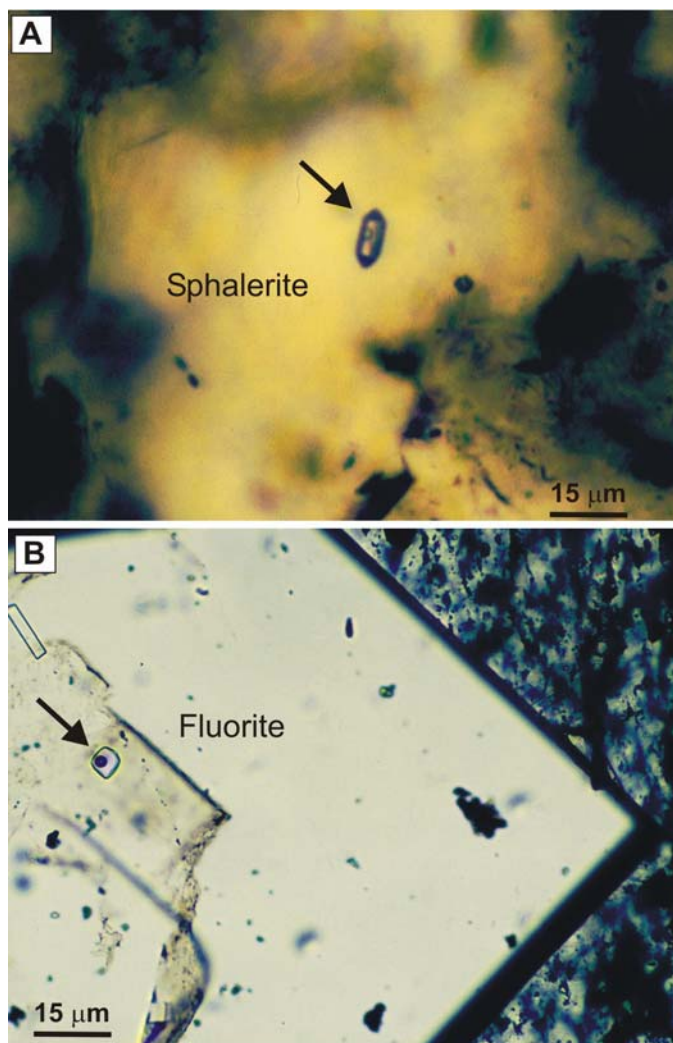


Chi and Lu, Fig. 3

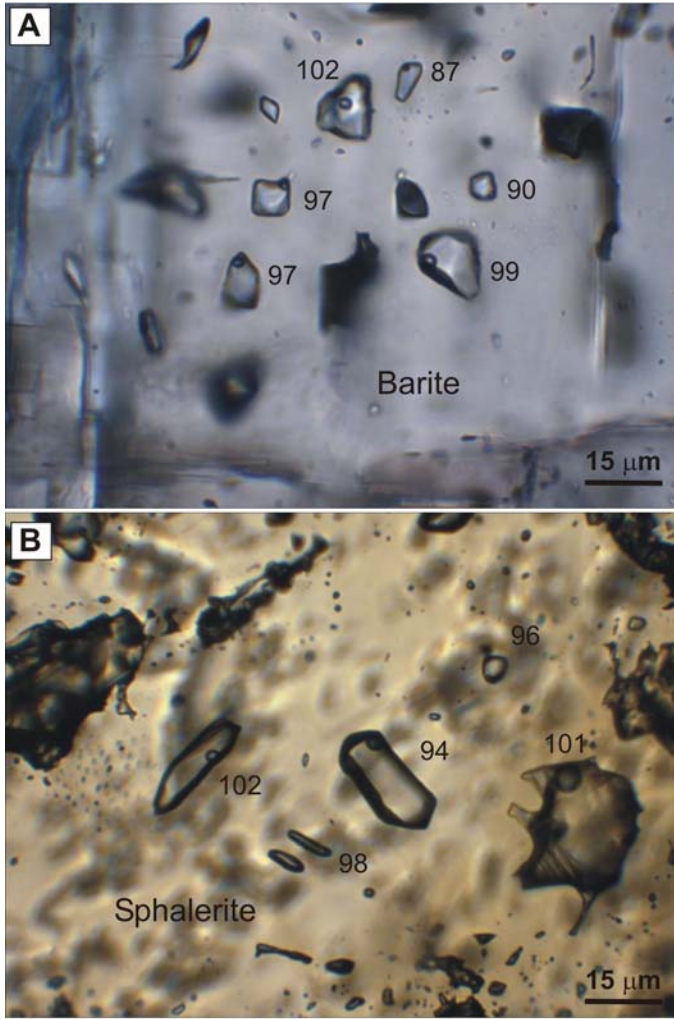




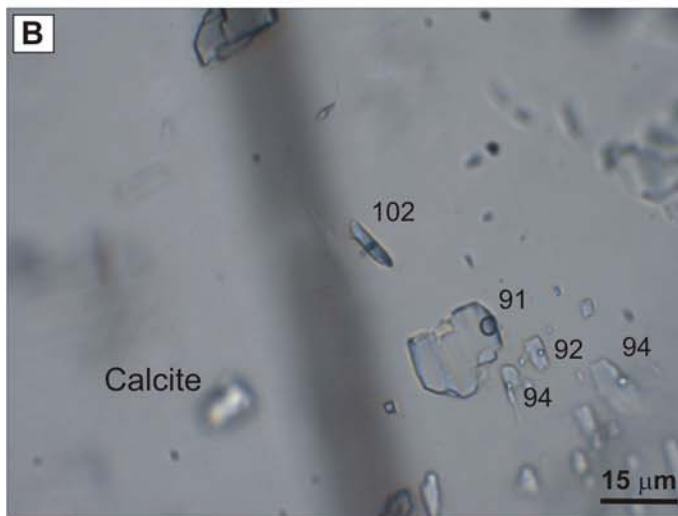
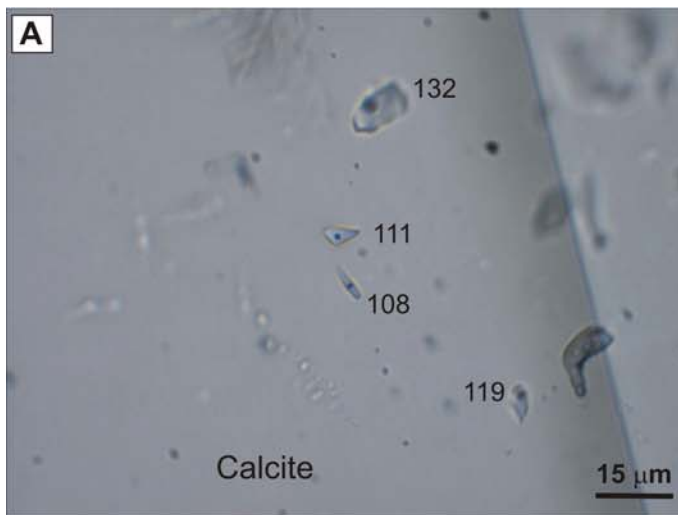
Chi and Lu, Fig. 4



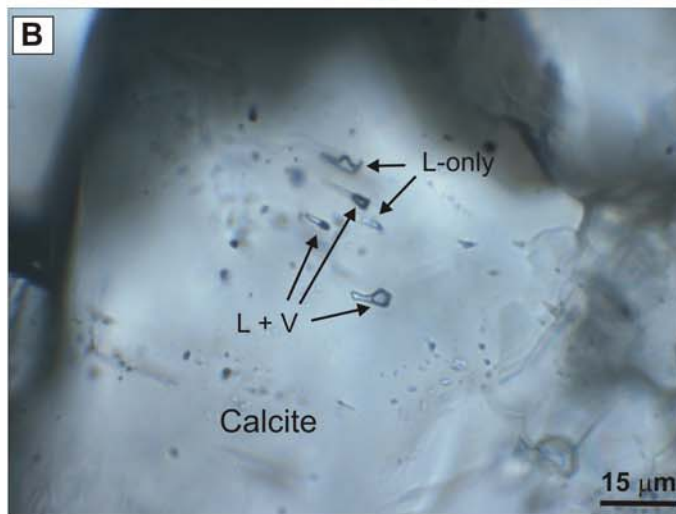
Chi and Lu, Fig. 5



Chi and Lu, Fig. 6



Chi and Lu, Fig. 7



Chi and Lu, Fig. 8

