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Possibilities and limits of infrared light microthermometry applied to studies of pyrite-hosted fluid inclusions

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Abstract

Pyrites from various occurrences and of different origin have been examined for fluid inclusions using an infrared microscope. Additionally, Fourier transform infrared spectroscopy was performed in order to characterize the infrared transmittance of individual samples in the spectral range of the IR TV camera ($\lambda \leq 2.5 \mu$ m) used. Studied samples of sedimentary pyrite are always opaque for near infrared light whereas pyrite from metamorphic rocks, hydrothermal ore deposits and pegmatites shows infrared transmittance of varying degree. Pyrite-hosted fluid inclusions are often opaque and only a few samples contain fluid inclusions which are suitable for microthermometric investigations. Ice melting temperatures of fluid inclusions in pyrite from three different occurrences were measured by direct observation on a monitor screen. When heating, the infrared transparency of pyrite decreases with increasing temperature due to shifting of the absorption edge to higher wavelengths. Therefore, most of the pyrites became opaque prior to reaching L-V homogenization. The only combined salinity and homogenization temperature data for fluid inclusions were obtained from pyrite samples from an argillic altered shear zone within the Murgul Cu deposit/NE Turkey. These pyrite crystals show up to 40% transmittance for infrared radiation in the wavelength range $\lambda = 0.8$ to 2.5 µm. Homogenization temperatures (Th) were measured visually up to temperatures of about 250°C. At higher temperatures the pyrite samples became completely opaque and Th values of fluid inclusions were obtained by a cycling technique. The data obtained from fluid inclusions as well as observed small fractionation of sulfur isotopic composition indicate that pyrite crystals with different morphologies (octahedrons, pentagondodecahedrons and combinations of both) from Murgul were deposited at different temperatures. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

The study of fluid inclusions in transparent minerals is a well established and powerful analytical method in geochemistry. Temperature and chemical composition data on fluid inclusions can be gathered by routine microthermometric investigations in visible light. Common gangue minerals such as quartz, carbonates, and fluorite are typically used, but only a few ore minerals, such as cassiterite, huebnerite, scheelite, and bright sphalerite, are suitable for this method. All other opaque ore minerals are excluded from traditional microthermometric investigations.

The applicability of infrared fluid inclusion microthermometry in wolframite, which is opaque un-

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der transmitted visible light, was first described by Campbell and Robinson-Cook (1987). During the following years several studies of fluid inclusions in wolframite were performed in order to obtain information about the depositional conditions of this mineral from various occurrences (Campbell et al., 1988; Campbell and Panter, 1990; Giamello et al., 1992; Lüders, 1996). The discrepancies of homogenization temperatures and salinity between fluid inclusions in wolframite and associated quartz disprove the idea of

Table 1

Sample localities, IR transmittance and fluid inclusion characteristics of studied pyrites

Sample locality	Source	Crystal shape	IR transmittance λ	Fluid inclusions		
			IR microscopically	FTIR (in percent)		
Lautenthal/Harz Mts. (Germany)	Devonian shales	framboid	opaque	0	_	
Rammelsberg/Goslar (Germany)	SEDEX deposit	massive	opaque	not tested	_	
Haselgebirge (Austria)	Zechstein Anhydr.	cube	opaque 0		_	
Altenkirchen (Germany)	shales	cube	opaque	0	-	
Siptenfelde/Harz Mts. (Germany)	olistostromes	massive	opaque	0	-	
Vlotho (Germany)	marls	cube	very low	not tested	-	
Lehesten (Germany)	shales	cube	patchy/low	not tested	not observed	
Minden (Germany)	sediments	cube	very low	not tested	not observed	
Navajun (Spain)	talc slate	cube	opaque	0.4	-	
Valdeparillo (Spain)	marls	pentagondodecah.	very low	1.8	-	
Chivar (Columbia)	black shales	cube	low/patchy	6.0	opaque	
Wittmannsgereuth (Germany)	metamorphites	cube	patchy	not tested	opaque	
Teuteburger Wald (Germany)	sediments	octahedron	low	not tested	not observed	
Hüttenberg/Kärnten (Austria)	marbles	cube	patchy	not tested	opaque	
Ivrea zone / Piemont	metamorphites	cube	good	not tested	mostly opaque,	
(Italy)	octahedron		patchy-good		some poorly	
		pentagondodecah.	good		transparent incs.	
Isola Elba (Italy)	metamorphites	cubes	patchy	10.0 - 11.5	opaque	
-	*	octahedrons	low	0.7 - 1.7	not observed	
		pentagondodecah.	low	1.5 - 1.7	not observed	
Wiluma mine (Australia)	Au-qz veins	massive	patchy	not tested	not observed	
Barra do Itapirapua	carbonatite-hosted	massive	good	not tested	mostly opaque,	
(Brazil)	mineralization	cube	-		locally transp. incs.	
Peru	volcanites	pentagondodecah.	good	not tested	opaque	
Freiberg/Saxony (Germany)	Pb–Zn–Ag veins	massive	good	10.3–12.0	not observed	
Schönbrunn (Germany)	fluorite veins	cube	patchy-good	not tested	nearly opaque	
Bingham/Utah (USA)	volcanites	massive	good	9.7-15.8	transp. fluid incs.	
Mazowe mine (Zimbabwe)	Au-qz veins	massive	good	12.5–19.3	transp. fluid incs.	
Pechtelsgrün/Saxony (Germany)	pegmat. qz cupola	cubes	good	14.7–19.2	transp. fluid incs.	
Murgul Cu deposit (Turkey)	altered volcanites	octahedrons	good	18.4-40.4	transp. fluid incs.	
		pentagondodecah.	good	14.2-38.7	transp. fluid incs.	

Abbreviations: qz = quartz, Anhydr. = anhydrite, pegmat. = pegmatitic.

coprecipitation of both minerals, even though they are often intimately intergrown. Other studies have shown that minerals, such as enargite (Mancano and Campbell, 1995), stibnite, tetrahedrite and bournonite (Lüders and Reutel, 1994; Lüders, 1996) are also suitable for infrared microthermometry.

Zoning and fluid inclusions in pyrite were first observed in transmitted IR light and documented by Richards and Kerrich (1993), although microthermometric data were not reported in their paper. The optical observations in near infrared light up to $\lambda = 1.9 \ \mu$ m indicate varying IR-transmittance for pyrite samples from various occurrences, and was explained as being due to the presence of As in excess of about 0.5 wt.% or even trace amounts of other elements (Richards and Kerrich, 1993).

Since the IR transmittance of a semi-conducting mineral such as pyrite strongly depends on its chemistry and crystal structure, which in turn define its electronic band structure and band gap energy, Fourier transform spectroscopy has been performed in the spectral range of commercially available IRsensitive TV cameras ($\leq 2.5 \,\mu$ m) in order to characterize the individual IR transmittance of pyrite samples from various occurrences and different origins (Table 1). Selected samples were analyzed by electron microprobe for iron, sulfur, and some trace elements in order to investigate a possible correlation between IR transmittance and trace element content distribution in pyrite. The main aim of this study is to demonstrate the applicability and limits of infrared microthermometry for the study of pyrite-hosted fluid inclusions.

2. Experimental

2.1. IR equipment and sample preparation

Fluid inclusions in doubly polished sections of pyrite were studied using a U.S.G.S. gas-flow heating/freezing system which is mounted on an Olympus BHSM-IR infrared microscope with long working distance, and high magnification IR objectives (up to $80 \times$). The thickness of the pyrite sections was chosen to be 90 µm, because thicker sections show too low a transmittance for IR light. The infrared image is transmitted to a monitor via a high-resolution Hamamatsu IR TV camera with a tube that has a maximal detection capability of about $\lambda \leq 2.5 \ \mu$ m (camera signal output current: $\geq 1 \ nA$ for 500 μ W). For microphotographic documentation, black and white prints were taken from the monitor by video printer. About 105 doubly polished sections of pyrites from 26 occurrences were prepared and petrographically scanned for fluid inclusions.

2.2. Fourier transform infrared (FTIR) spectroscopy

The transmission spectra of individual pyrite samples in the near-IR region (NIR) yield information about the variation of IR transmittance as a function of the wavelengths and also the position of the absorption edge which is controlled by the band gap energy. This information can be used to preselect samples which may be suitable for infrared microthermometric investigation (Ziemann and Lüders, 1996). Spectra were obtained from doubly polished sections of pyrite (90 µm) using a Perkin Elmer model 2000 FTIR spectrometer. All pyrite spectra were measured in the NIR using a 100 µm aperture. In addition, FTIR spectra of a pyrite sample from Murgul (Turkey) were measured in a modified metal chamber of a U.S.G.S. gas-flow heating/freezing stage over a temperature range of 20 to 100°C, in order to investigate changes in IR transmittance with temperature.

2.3. Electron microprobe analyses

Electron microprobe analyses on selected pyrite samples of different origins, i.e., sedimentary, hydrothermal and pegmatitic, were made gathering data for the Fe and S ratios, and the element concentrations of Co, Ni, Cu, Zn, Ga, As, Ag, Sb, Te, and Bi. The analyses were performed using the CAMECA SX-100 electron microprobe with the data reduction package employing the PAP-correlation procedure. The operation conditions were an accelerating potential of 20 kV, current of 20 nA on Faraday-cup and $2-3 \mu m$ beam diameter. The counting times for Fe and S were 20 s, and 60 s for trace elements, respectively. Sulfides, oxides and pure metals were

Election interoprobe analyses of selected pyrite samples (for further details see Table 1)											
Sample wt.%	No.1 ^b	No.2 ^a	No.3 ^a	No.4 ^a	No.5 ^a	No.6 ^a	No.7 ^a	No.8 ^a	No.9 ^b	No.10 ^a	No.11 ^b
S	53.81	53.44	53.29	53.31	54.01	53.17	54.27	53.68	53.14	53.61	53.08
Fe	45.87	45.99	46.18	45.94	46.45	46.50	45.76	46.49	45.55	45.73	46.38
Co	0.01	0.12	0	0	0	0.10	0	0.01	0.04	0	0.01
Zn	0	0	0	0	0	0	0.02	0	0	0	0
Ga	0	0	0	0	0	0	0.02	0.01	0	0	0
As	0.03	0.01	0	0	0.01	0.23	0.04	0.03	0.03	0	0.01
Total	99.72	99.56	99.47	99.25	100.47	100.00	100.11	100.22	98.76	99.34	99.48
IR-transparency	opaque	opaque	opaque	opaque	opaque	patchy	patchy	good	good	good	good

Table 2 Electron microprobe analyses of selected pyrite samples (for further details see Table 1)

Ni, Cu, Ag, Sb, Te, Bi were all below detection limits in all samples.

^aAverage of 50 analyses/sample; ^baverage of 100 analyses/sample. Key to localities: no. 1—Devonian slate-hosted pyrite framboid (Harz Mts., Germany); no. 2—Reiche Zeche (Freiberg, Germany); no. 3—Zechstein-hosted pyrite (Haselgebirge, Austria); no. 4—Valdeparillo (Spain); no. 5—Rammelsberg (Harz Mts., Germany); no. 6—Isola Elba (Italy); no. 7—Mazowe Mine (Harrare, Zimbabwe); no. 8—Bingham (Utah, United States); no. 9—Pechtelsgrün (Saxony, Germany); no. 10—octahedral pyrite (Murgul, Turkey); no. 11—pentagondodecahedral pyrite (Murgul, Turkey).

used as standards. The results of the microprobe analyses are given in Table 2.

3. Results

3.1. IR characteristics of pyrite

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Samples of pyrite in this study which originate from diagenetic processes in sediments show no or

Transmittance (%)

very low IR transmittance in the spectral range of the IR TV camera (Table 1, Fig. 1). The highest transmittance of about 6% at $\lambda = 2.5 \,\mu$ m was shown by a black shale-hosted pyrite sample from the emerald occurrence in Chivar, Columbia (Fig. 1). This sample also shows an increased IR transmittance at $\lambda = 1.7 \,\mu$ m. No transparency was observed on the monitor for this sample, indicating that transmittance of more than 4 to 6% is needed for optical observa-

a

b

c d



TV Camera

Wavelength (micrometers)

Fig. 1. FTIR spectra of sedimentary pyrites (90 μ m thick sections) from various occurrences obtained using a Perkin Elmer FT-IR model 2000. The spectral range of the IR TV camera lies to the left of the dashed line. Key to localities: (a) Chivar, Columbia, (b) Valdeparillo, Spain, (c) Navajun, Spain, (d) Haselgebirge, Austria, (e) Lautenthal, Germany.

tion. An increase of IR transmittance for some well crystallized sedimentary pyrites (Valdeparillo and Navajun, both Spain; Haselgebirge, Austria) was observed at wavelengths well above 2.2 μ m, whereas a shale-hosted pyrite framboid from the Harz Mts., Germany did not show any IR transmittance in the wavelength range between 1.0 and 4.3 μ m (Fig. 1).

In contrast, the pyrite samples from hydrothermal mineralization and metamorphic rocks show variable IR transmittance in the spectral range 1.0 to 2.5 μ m (Table 1, Fig. 2). The FTIR spectra indicate the highest transmittance for infrared radiation for pyrite crystals from the Murgul Cu deposit in NE Turkey (Fig. 2). These samples originate from a NNE-SSW striking shear zone within the western central part of the deposit. The dacitic tuff within this shear zone is overprinted by an advanced argillic alteration and contains numerous euhedral octahedral and less abundant pentagondodecahedral pyrite crystals. Combinations of these two crystal types such as cubes or dodecahedrons are locally observed. Quartz and carbonates, that are normally abundant in veins and fissures, do not occur within the argillic altered shear zone (Rezvan-Dezfouli, 1993). Other pyrite samples which also show good IR transmittance (up to 20%) in the spectral range of the IR TV camera originate from gold–quartz veins of the Mazowe mine near Harrare, Zimbabwe and from the quartz cupola of the Pechtelsgrün pegmatite in Saxony, Germany (Fig. 2).

Electron microprobe analyses indicate that none of the pyrite samples studied show significant differences in Fe to S ratios, and they consistently show low trace element concentrations of Co, Ni, Cu, Zn, Ga, As, Ag, Sb, Te, and Bi (Table 2). From this data, no correlations between trace element content and individual IR transmittance of pyrite were observed.

3.2. Fluid inclusions in pyrite

3.2.1. Fluid inclusion petrography

All samples of pyrite which show good IR transmittance have been examined for fluid inclusions. In some pyrite crystals, fluid inclusions show no or only poor transparency for NIR light (Table 1, Fig. 3a). Richards and Kerrich (1993) only observed dark fluid inclusions in the pyrite samples that they studied, and attributed the opacity of pyrite-hosted fluid inclusions to an intense refraction of light resulting from the high refractive contrast between pyrite and aqueous fluids. Similar opaque inclusions are also



Fig. 2. FTIR spectra of hydrothermal and pegmatitic pyrites (90 µm thick sections). Key to localities: (a) Murgul Cu deposit, Turkey, (b) Pechtelsgrün, Germany, (c) Mazowe mine, Zimbabwe, (d) Bingham, USA.



Fig. 3. Infrared photomicrographs of fluid inclusions in pyrite. The scale bar of 50 μ m in (d) is also representative for a, c and e. (a) Trail of opaque fluid inclusions decorating growth zone in pyrite (Cerro de Pasco, Peru). (b–d) Two phase fluid inclusions in pyrite from Murgul, Turkey (for details see text). (e) Primary two-phase fluid inclusion in pegmatitic pyrite (Pechtelsgrün, Germany). (f) Fluid inclusions in pyrite from Murgul (Turkey) surrounding rock fragment (not shown on photomicrograph).

observed in tetrahedrite, dark sphalerite, sulfosalts, and wolframite. A further effect of infrared light absorption by fluid inclusions might be, that due to post-entrapment reactions of the fluid with the host mineral, rims of solids that absorb near infrared light precipitated around the inclusion walls. This assumption is based on observations in pyrargyrite from St. Andreasberg (Harz Mts., Germany) which contains opaque inclusions that show typical features of secondary stress (e.g., necking-down). PIXE analyses indicate the presence of loellingite in these inclusions which has a low band gap energy similar to that of arsenopyrite (0.2 eV) and, therefore, is opaque for NIR light.

The observed fluid inclusions in pyrite always contain an aqueous phase and a vapor bubble. They

mostly occur in trails or groups and show elongated or irregular forms (Fig. 3b). Vertical or zig-zag patterns of elongated fluid inclusions are often abundant (Fig. 3c). Sometimes the inclusions exhibit disc-shaped internal structures (Fig. 3d). At first glance, the presence of an additional CO₂ phase in these inclusions may be suggested. However, the IR light source causes heating of the sample up to about 35°C, well above the critical point of CO₂. Therefore, it can be concluded, that these inclusions do not contain an observable CO_2 phase. It should be noted that fluid inclusions in studied pyrite crystals are mostly large (> 30 μ m) and locally their lengths may exceed 150 µm. A classification of primary. pseudosecondary, and secondary inclusions in pyrite is difficult. Isolated inclusions which might be classified as primary inclusions are rare (Fig. 3e). However, trails of elliptic or elongated inclusions which are orientated parallel to growth zones might be classified as primary or pseudosecondary in origin. Commonly, in cases where fragments of rocks are overgrown by pyrite, concentric whirls of inclusions with convex shapes surround these fragments (Fig. 3f).

3.2.2. Microthermometry

During freezing runs the quality of IR transparency of pyrite does not change. In none of the inclusions was the nucleation of an additional gas bubble (such as CO_2 or CH_4) observed.

In samples from the Murgul Cu deposit first melting of ice was observed between -13.5° C and -10.5° C for inclusions in pentagondodecahedral pyrites, and between -11.0° C and -8.6° C for inclusions in octahedrons. The final ice melting temperatures of fluid inclusions in pentagondodecahe-

dral pyrites lie between -5.2° C and -2.9° C, which corresponds to salinities of 8.1-4.7 eq. wt.% NaCl (Table 3). Fluid inclusions in octahedral pyrites show final ice melting temperatures between -3.2° C and -2.0°C (5.2-3.3 eq. wt.% NaCl). Fluid inclusions in combinations of both crystal types (cubes, dodecahedrons) show first melting between -12.0° C and -8.2°C and final ice melting temperatures between -3.4° C and -1.8° C (5.5–3.0 eq. wt.% NaCl). The final ice melting temperatures of fluid inclusions in pyrite from the Mazowe mine lie between -1.8° C and -1.3° C (3.0–2.1 eq. wt.% NaCl). Fluid inclusions in pyrite from the Pechtelsgrün pegmatite are scarce. The only two inclusions which were measured show final ice melting temperatures of -1.1° C and -0.9°C (1.8-1.5 eq. wt.% NaCl). Coupled melting of clathrate or hydrate was not observed in any fluid inclusion during cryometric measurements.

During heating, the IR transparency progressively decreases with increasing temperature. At temperatures between 130°C and 160°C pyrites from the Mazowe mine and Pechtelsgrün become completely opaque prior to reaching the homogenization temperature of two-phase fluid inclusions. A similar effect is also observed for samples from the Murgul Cu deposit, but homogenization events in octahedral pyrites in the temperature range between 212.1°C and 254.3°C could mostly be measured by direct observation on the monitor screen (Table 3). All inclusions show homogenization of the vapor into the liquid phase. At temperatures above 250°C only a few directly measured homogenization temperatures could be obtained, because the samples become opaque. In order to investigate this phenomenon, FTIR measurements in the temperature range between 20°C and 100°C were performed on an octahe-

Table 3

Fluid inclusion microthermometric data of pyrites from the Murgul Cu deposit, Mazowe mine/Zimbawe and Pechtelsgrün/Germany

Locality	Host	Salinity eq. wt	.% NaCl	Homogenization temperature (°C)		
		Range	Mean (N)	Range	Mean (N)	
Murgul	Pyrite Pentagondodecahedrons	4.70-8.1	6.29 (31)	298.0-319.0	307.0 (26)	
	Pyrite Octahedrons	3.28-5.17	4.51 (24)	212.1-254.3	228.6 (16)	
	Pyrite Combinations	2.96 - 5.47	4.01 (10)	275.5-322.0	292.0 (7)	
Mazowe mine	Pyrite massiv	2.14-2.96	2.47 (3)	> 130		
Pechtelsgrün	Pyrite cube	1.49-1.82	1.66 (2)	> 160		

dral pyrite from Murgul. Within this short temperature interval, the absorption edge is shifted by 0.06 μ m to higher wavelengths (Fig. 4). From these spectra a change of the band gap energy from 0.91 to 0.87 eV can be derived. The FTIR spectra also indicate that for the sample studied the decrease of IR transparency is only caused by the shift of the bad gap energy, whereas the IR transmittance keeps nearly constant at higher wavelengths.

Due to the strong IR absorption above 250° C, cycling heating runs, similar to the cyclic method described by Goldstein and Reynolds (1994), were performed in order to obtain the homogenization temperatures of fluid inclusions in pentagondodecahedral pyrites. During the first heating runs at temperatures above 250° C, increments of 10° C were chosen to achieve the temperature of homogenization. If, for example, the detected Th value of an inclusion lies between 300° C and 310° C, the temperature increments during the next heating runs were lowered to 5° C and finally 1° C in order to obtain an accuracy of $\pm 1^{\circ}$ C (Table 3). In the subsequent discussion, only fluid inclusion data which showed a

spontaneous nucleation of the vapor phase upon cooling, indicating that Th was reached, were used. During cycling heating runs no evidence for stretching or leakage of the studied inclusions was observed. In two cases, the homogenization of the vapor into liquid phase could be measured directly for fluid inclusions in a pyrite cube (275.5°C, 280.2°C). The other Th values between 284 and 322°C were obtained by cyclic Th measurements (pyrite combinations in Table 3).

3.3. Discussion of the fluid inclusion data in pyrites from Murgul

The microthermometric data of fluid inclusions in pyrite crystals from an argillically altered shear zone within the Murgul Cu deposit indicate that octahedral and pentagondodecahedral pyrites precipitated from low to medium-salinity fluids. The minimum crystallization temperatures of pyrites can be derived from the homogenization temperatures of two-phase fluid inclusions which range between 229°C and



Fig. 4. FTIR spectra of a pyrite thick section (90 μ m) from the Murgul Cu deposit showing the temperature-dependent shift of the absorption edge to higher wavelengths.

307°C (Fig. 5). The variations of Th and salinity of inclusions in crystals combining both octahedrons and pentagondodecahedrons fall in between the two fields of fluid inclusion data for separate octahedral and pentagondodecahedral pyrites (Fig. 5). Eutectic melting temperatures between -13.5 and -10.5° C of fluid inclusions in pentagondodocahedrons lie mostly below the eutectic of the H₂O-KCl system $(-10.6^{\circ}C)$ and indicate the presence of other cations. most probably sodium, in the ore-forming fluid. Fluid inclusions in octahedral pyrites could be interpreted as nearly pure H₂O-KCl fluids due to their eutectic temperatures $(-11 \text{ to } -8.6^{\circ}\text{C})$. Since the salinity of all liquids is fairly uniform, the variation of Th values of fluid inclusions in different crystal types can be explained simply by cooling of the ore-forming fluid. The difference between the mean Th values of fluid inclusions in octahedral and pentagondodecahedral pyrites is nearly 80°C. Th values of fluid inclusions in combined crystals fall in between (Fig. 5).

From an earlier study by Rezvan-Dezfouli (1993), the sulfur isotopic composition of some of the microthermometrically examined samples is known.

The δ^{34} S values of the samples of pentagondodecahedral and octahedral pyrites fall in a tight range between +4.6 and +5.3% (+0.1%). At the first glance, these data are fairly uniform and suggest a homogeneous sulfur source. But it is noteworthy that octahedral pyrites show slightly higher mean δ^{34} S values (+5.2%) than pentagondodecahedral pyrites (+4.7%). Using the measured mean Th variation of fluid inclusions in octahedral and pentagondodecahedral pyrites, a fractionation factor of about 0.55 (= 0.55%) for $\Delta \text{ oct.pyrite} - H_2 S$ (229°C)- Δ pent.pyrite-H₂S (307°C) can be derived based on experimentally measured data (Ohmoto and Rye. 1979). This calculated value is nearly consistent with the difference of the mean δ^{34} S values of pyrite octahedrons and pentagondodecahedrons (which is about 0.5%), although the Th values used for calculation of the fractionation factor for pyrite and H₂S only represent the minimum temperatures for pyrite precipitation. Nevertheless, microthermometric data and observed fractionation in sulfur isotopic composition reflect, that crystallization of individual shapes. in the case of the studied pyrites from the Murgul Cu deposit, is likely temperature-controlled.



Fig. 5. Homogenization temperature vs. salinity diagram of fluid inclusions in octahedral and pentagondodecahedral pyrites and crystal combinations thereof.

4. Conclusions

The applicability of infrared microthermometry for studies of fluid inclusions in pyrite is very restricted and controlled by the individual IR transparency of the sample which can also be characterized by FTIR spectroscopy. The FTIR spectra can be used for a general preselection of samples. Internal features and fluid inclusions are only clearly observed in pyrite that displays an infrared transmittance of more than 20% in the wavelength range between at $\lambda = 0.8-2.5 \ \mu$ m. Under this prerequisite many pyrites (incl. most sedimentary pyrites) are excluded from IR microscopic investigations. A further problem arises from the common opacity of pyrite-hosted fluid inclusions themselves.

Cryometric measurements of IR transparent fluid inclusions in pyrite are occasionally possible, but direct observations of Th are limited by the decreasing IR transparency of pyrite with temperature. For individual crystals with high IR transmittance this problem can be circumvented by the use of a cycling technique for heating runs as described by Goldstein and Reynolds (1994).

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