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GEOLOGICAL SURVEY

Mineralization in the Waning Creede Epithermal System, and Similar Behavior in Other Systems

by

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This report includes the transcript and figures of a talk presented at the national Geological Society of America Meeting, Phoenix, Arizona, October, 1987 (Plumlee and Rye, 1987).

Slides presented in the talk are reproduced here in black and white, and labeled as "SLIDE LEFT 1", "SLIDE RIGHT 1", etc., at the appropriate points in the text. The slides were shown in pairs in the talk: SLIDE LEFT refers to the slide on the left-hand screen, while SLIDE RIGHT refers to the slide on the right-hand screen. Printing in italics is added for the clarification of this report, and was not included in the original talk as presented.

INTRODUCTION

Mineralization deposited in the late, waning stages of hydrothermal systems has generally received little attention in ore deposit research; it is typically poorly developed and of little economic value. However, our detailed studies of well-developed late-stage epithermal mineralization at Creede, Colorado, have revealed much about the chemical and hydrologic processes that occur in waning hydrothermal systems. Our understanding of the waning Creede system can also be applied to mineralizing processes in shallow hot-spring gold, mercury, and silver deposits.

SLIDE LEFT 1 - *Schematic model of Creede hydrothermal system hydrology*
SLIDE RIGHT 1 - *Written Creede system hydrology*

Creede is a volcanic-hosted epithermal vein deposit located in southwestern Colorado. In order to understand the waning Creede hydrothermal system, we must first consider briefly what the system hydrology looked like during main mineralization stages. A schematic model of the main stage Creede hydrology is depicted in the north-south long section shown on the left. Note the system's upwelling plume, outlined by the 200°C isotherm. Ore deposition occurred along the top of the plume in response to boiling and lateral mixing with dilute ground waters overlying the plume. The groundwaters were relatively hot and acidic due to the condensation of gases boiled from the plume below. Make note of these groundwaters, for they played an important role in the late-stage mineralizing processes at Creede. *For recent summaries of the extensive research at Creede, the reader is referred to Bethke (1987), Rye et al. (1987), Hayba (1987), Foley et al. (1987), Barton (1987), Plumlee et al. (1987), Bethke and Lipman (1987), Hayba et al. (1985).*

SLIDE LEFT 2 - *Photo, late-stage Creede botryoidal pyrite*
SLIDE RIGHT 2 - *Photomicrograph*

As the Creede hydrothermal system waned, it deposited distinctive late-stage botryoidal pyrite and marcasite, with lesser stibnite, sphalerite, and pyrargyrite. A photo of the botryoidal pyrite on the left shows a thick crustification sequence coating earlier main stage sulfides. On the right, a reflected light photomicrograph of the sample's early stratigraphy shows marcasite, banded pyrite, and stibnite. The field of view is 2 mm wide. Microprobe analyses show that the brown *(dark)* pyrite bands are exceptionally enriched in arsenic, antimony and silver, with combined concentrations in the pyrite up to 13 weight percent.

These late-stage mineralogies were deposited primarily in the uppermost ore zones of all vein systems in the district.

SLIDE LEFT 3 - *Photo, late-stage Creede botryoidal pyrite and marcasite*
SLIDE RIGHT 3 - *Plot, $\delta34S$ and trace element variations*

Fine-scale, stratigraphically controlled sampling across many late-stage pyrite stratigraphies has revealed extreme sulfur isotope values which covary with trace element compostion. In the OH vein pyrite sample shown on the left, a total sulfur isotope range of 65 ‰ has been measured, a rather extraordinary range for a volcanic-hosted epithermal deposit. The bronze bands *(bands labeled -4‰ and -29‰)* are pyrite, the green *(band labeled +35‰)*, marcasite . As shown in the plots of $\delta^{34}S$ and trace element contents across the same sample's stratigraphy shown on the right, the heaviest $\delta^{34}S$ values occur in the marcasite, whereas the lightest $\delta^{34}S$ values occur late in the outermost arsenic- and antimony-rich pyrite. Note the 65 ‰ range in the sample is accounted for across less than 2 mm stratigraphically, dropping from +32 ‰ to -29 ‰!

The same general stratigraphy of pyrite growth zones, with similar trends over time of trace element contents, sulfur isotope composition and accessory minerals, can be correlated throughout the district *(Plumlee and Rye, 1986).*

In order to interpret how this isotopically and compositionally distinctive late-stage mineralization formed, we must consider several lines of evidence.

SLIDE LEFT 4 - *Late-stage Creede chemical environment*

First, we can place some constraints on the late stage chemical environment. Based on limited fluid inclusion data (Woods et al., 1982), fluid temperatures at the beginning of late-stage pyrite deposition were probably below 200°C, and dropped rapidly as the stage proceeded. Contemporaneous decreases in fluid salinities are also indicated, suggesting an influx of dilute groundwaters into the sytstem as it started to wane.

The presence of contemporaneous marcasite and pyrite suggests relatively acid pH values, in the range from 4.5 to 5. The lack of pyrrhotite or hematite suggests that the fluid chemistries were moderately oxidizing. The presence of famatinite, the antimony analog of enargite, requires moderately high sulfidation conditions. Finally, the chemical conditions were such that the low-temperature "mobile" epithermal elements such as arsenic and antimony were present in abundance.

SLIDE LEFT 5 - *Creede δD - $\delta^{18}O$ isotope plot*

The hydrogen and oxygen isotope compositions of late stage inclusion fluids, when compared with those of main-stage fluids, indicate a late-stage influx of meteoric waters into the system; as shown by fluid inclusion data, the meteoric waters were dilute and of lower temperature. We believe this influx reperesents the collapse of shallow overlying groundwaters into the deeper vein systems, accompanying the thermal collapse of the waning Creede hydrothermal system.

SLIDE LEFT 6 - *Main-stage sulfide $\delta^{34}S$ histogram*
SLIDE RIGHT 6 - *E-stage (Late-stage) sulfide $\delta^{34}S$ histogram*

Main stage sulfur isotope variations at Creede, shown on the left, are restricted to a narrow range of several per mil around zero. In contrast, the total range of sulfur isotope variations measured in the late stage sulfides, shown on the right, is a whopping 92 ‰, from -44 ‰ to +48 ‰! As the system waned, isotopically variable biogenic sulfur from nearby caldera moat sediments probably began to dominate over 0 ‰ igneous sulfur in the hydrothermal fluids. The Creede caldera moat to the south provided isotopically heavy sulfur, whereas northern moat sediments[1] possibly provided isotopically light sulfur.

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[1] *Buried blocks of bedded lacustrine carbonates with diagenetic pyrite ($\delta^{34}S$ = -15‰, Plumlee and Rye, 1986) and sulfur-bearing organic matter ($\delta^{34}S$ = -10‰, Plumlee and Rye, 1986) have been encountered in drill core in the northern district (samples for analysis provided by Homestake Mining Co.). Although of*

Sedimentary sulfur input alone, however, cannot account for all of the late-stage variations. We feel that kinetic processes must have further fractionated the sedimentary sulfur to produce the extreme values seen at either end of the spectrum.

SLIDE LEFT 7 - *Fractionations during thiosulfate disproportionation*
SLIDE RIGHT 7 - *Causes for extreme $\delta^{34}S$ variations at Creede*

The low-temperature, moderately oxidizing, acidic, and sulfidizing late-stage chemical environment probably promoted the formation of metastable intermediate-valency sulfur species such as polysulfides, thiosulfates and sulfites *(Murowchick and Barnes, 1986)*. Polysulfide generation probably created the extreme supersaturations needed to produce the botryoidal textures seen in the late pyrite. Additionally, the disproportionation of thiosulfate and sulfite species could potentially have produced extreme isotope fractionations. On the left, possible scenarios are shown for the 150°C disproportionation of thiosulfate derived from various sources. This is based on data by Uyama et al. *(1985)*. The extreme negative late-stage sulfur values could have come from the disproportionation of thiosulfate species formed by the oxidation of -15 ‰ northern moat sulfur.

The extreme positive late-stage sulfur isotope values most likely involved the reduction of heavy sulfate from southern moat sediments. This may have been accomplished by acid-catalyzed reactions of H_2S with sulfate species, by thermochemical reduction of sulfate by organic matter, or, if temperatures were below 110 °C, by bacteriogenic sulfate reduction.

SLIDE LEFT 8 - *Main-stage Creede ore zone hydrology*
SLIDE RIGHT 8 - *Late-stage Creede ore zone hydrology*

By integrating all of this information, we have developed a fairly detailed understanding of the waning Creede hydrothermal system. Schematic models of the main- and late-stage Creede ore zone hydrology are compared on the left and right. During main stages, mixing of hot hydrothermal fluids and overlying steam-heated groundwaters triggered base metal sulfide, silver, and barite deposition in the ore zone. Botryoidal pyrite deposition may have occurred on the low-temperature fringes of the system where the hydrothermal fluids mixed with cool, iron bearing groundwaters. As the system waned thermally, oxidizing, acidic, cool groundwaters overlying and surrounding the system began to collapse into the deeper veins. The groundwaters were likely acidified through the condensation of acid volatiles, or through the oxidation of wallrock sulfides and hydrothermal sulfides in the upper parts of the system. The late-stage pyrite, marcasite and other sulfides were deposited at the mixing interface between the groundwaters and low temperature hydrothermal fluids. The hydrothermal fluids were likely enriched in "mobile" epithermal elements. The extreme sulfur isotope variations probably reflect the input of shallow sedimentary sulfur into the system, coupled with fractionations accompanying various non-equilibrium sulfur chemistry processes.

SLIDE LEFT 9 - *Photograph, late-stage marcasite, pyrite, alunite from Lake City, CO*
SLIDE RIGHT 9 - *Lake City summary*

Through a survey of the literature, and through our studies, we have noted similar occurrences of isotopically and/or compositionally distinctive late-stage pyrite, marcasite, and other sulfides. These occurrences span a wide range of deposit types. Most are not as well developed as those at Creede, and so have not been examined in great detail. The few unusual late-stage sulfur isotope numbers that have been noted in the literature at a number of deposits are generally not adequately interpreted. Our knowledge of Creede has given

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uncertain extent, these sediments are most likely moat sediments filling parts of the northern Bachelor caldera (D. Sawyer, pers. comm., 1987).

us a framework in which to interpret these late-stage occurrences, which we feel are fundamental manifestations of waning hydrothermal systems.

For example, in the epithermal deposits at Lake City, Colorado, samples provided to us by John Slack from the upper levels of some vein systems contain late-stage plumose marcasite, botryoidal pyrite, and alunite. Barite and chalcedony have also been noted as late-stage minerals at Lake City *(Slack, 1980)*, although they do not occur in the sample shown here. The massive brown material *(dark gray)* coating the plumose marcasite in the sample on the left is alunite, happily compatible with a late-stage oxidizing, acidic chemistry. Limited probe analyses show that the pyrite is enriched in arsenic, antimony, and tellurium. Based on limited sulfur isotope analyses to date, the late-stage sulfides appear to be somewhat lighter isotopically than main-stage sulfides.

SLIDE LEFT 10 - *Photograph, late-stage botryoidal pyrite from Julcani, Peru*
SLIDE RIGHT 10 - *Julcani summary*

In the base metal and silver lode deposits at Julcani, Peru, late stage arsenic- and antimony-rich botryoidal pyrite and marcasite occur with siderite and galena. Beautiful botryoidal pyrite from Julcani is shown on the left (samples provided by Jeff Deen). Jeff has shown that, although main stage sulfides show sulfur isotope variations indicative of sedimentary sulfur input, the late stage-sulfides do show a wide range of $\delta^{34}S$ values compared to main stage sulfides *(Deen et al., 1987).*

SLIDE LEFT 11 - *Photograph, late-stage Pb-As-S glass from Cerro de Pasco, Peru*
SLIDE RIGHT 11 - *Cerro de Pasco summary*

At Cerro de Pasco, another base metal lode deposit, the late-stages are dominated by widespread hydrothermal leaching, and by the deposition of various silver sulfides and unusual lead-arsenic-sulfide glass *(Lacy and Hosmer, 1956).* A photograph of the glass, termed revoredoite, is shown on the left*; the sample is from the South American Economic Mineral Collection, Harvard University.* Jensen *(1959)* measured extremely light sulfur isotope values in the silver sulfides and sulfide glass; this suggests to us that the late-stage at Cerro de Pasco is a variation on the theme of the collapse processes we've documented at Creede. Hydrothermal leaching would be fully compatible with the influx of acidic, oxidizing groundwaters into the deeper veins.

SLIDE LEFT 12 - *Photograph, late-stage botryoidal siderite and pyrite from San Cristobal, Peru*
SLIDE RIGHT 12 - *San Cristobal summary*

Arsenic-and antimony-bearing botryoidal pyrite occurs with marcasite, manganiferous siderite, and botroidal sphalerite as late-stage minerals in the manto deposits at San Cristobal, Peru *(Bartlett, 1984).* On the left, the manganiferous siderite coats botryoidal pyrite. The relatively few sulfur isotope measurements on late stage material which we and Bartlett *(1984)* have made reveal an extreme range of late-stage sulfur isotope variations.

SLIDE LEFT 13 - *Photograph, late-stage botryoidal pyrite, Jachyma, Czeckoslovakia*
SLIDE RIGHT 13 - *Jachyma summary*

On the left, a reflected light view of etched botryoidal pyrite from the cobalt-nickel-arsenide veins of Jáchyma, Czechoslovakia *(long dimension = 2 mm).* Sulfur isotope measurements which we've made on this sample of botryoidal pyrite *(supplied to us by the Smithsonian Institution Museum of Natural History)* show that the late-stage pyrite is quite light, ranging from *-20‰* to *-24‰.* At present we do not know how these values compare to those for main-stage sulfides.

SLIDE LEFT 14 - *Photograph, late-stage marcasite, Upper Mississippi Valley*
SLIDE RIGHT 14 - *Upper Mississippi Valley summary*

Abundant late marcasite occurs in the Upper Mississippi Valley district MVT's. McLimans *(1977)* showed that sulfur isotope compositions of main-stage sphalerite, galena and marcasite from the central parts of the district stayed relatively constant over time. The late-stage marcasite becomes isotopically heavier than in main stages, while the late-stage galena and sphalerite become isotopically lighter. Intriguingly, in a paper given at this meeting, Kutz and Spry *(1987)* documented extreme main-stage sulfur isotope variations of -22‰ to +23‰ in samples from the low-temperature fringes of the district.

SLIDE LEFT 15 - *Photograph, pyrite oolites from thermal springs, Kamchatka Peninsula, USSR*
SLIDE RIGHT 15 - *Kamchatka thermal springs summary*

Isotopically and compositionally distinctive botryoidal pyrite and marcasite are also noted in a number of shallow thermal springs and hot spring gold deposits. For example, oolitic pyrite with high arsenic and mercury contents are currently forming in thermal springs on the Kamchatka Islands, USSR. This pyrite is -41‰, has high arsenic and mercury contents, and textures identical to that of the Creede pyrite *(Ozerova et al., 1971).*

SLIDE LEFT 16 - *Late-stage pyrite/marcasite occurrences*
SLIDE RIGHT 16 - *Conclusions - Chemical variations on the theme*

In conclusion, the list of hydrothermal ore deposits in which isotopically and/or chemically distinctive late-stage pyrite and marcasite occurs is extensive, and includes a broad range of hydrothermal ore deposit types. We would like to propose that many, if not all, of these similar occurrences reflect processes that are common to and a fundamental part of waning hydrothermal systems: the collapse of oxidizing, acidic groundwaters into deeper ore zones.

We also propose that late-stage mineralogies other than pyrite and marcasite that are seen in many hydrothermal deposits may simply reflect chemical variations on the same basic collapse process. These include deposition of barite, isotopically heavy carbonates, chalcedony and sulfide glasses, and hypogene leaching.

SLIDE LEFT 17 - *Shallow pyrite/marcasite occurrences*
SLIDE RIGHT 17 - *Conclusions - Hot spring deposits*

Finally, a number of isotopically and compositionally distinctive pyrite and marcasite occurrences are also noted in shallow, low-temperature hot spring deposits. These suggest that the mixing, acidification, and oxidation processes we postulate for the deep ore zones in waning hydrothermal systems are also active at low-temperature, shallow levels of hot spring systems. The unusual sulfur numbers again imply non-equilibrium sulfur chemistries. Because gold is so strongly complexed by sulfur in solution, the possible occurrence of metastable sulfur species and other non-equlibrium sulfur chemistries may strongly affect gold transport and depostion in the hot spring environment. We are currrently evaluating these possiblities further.

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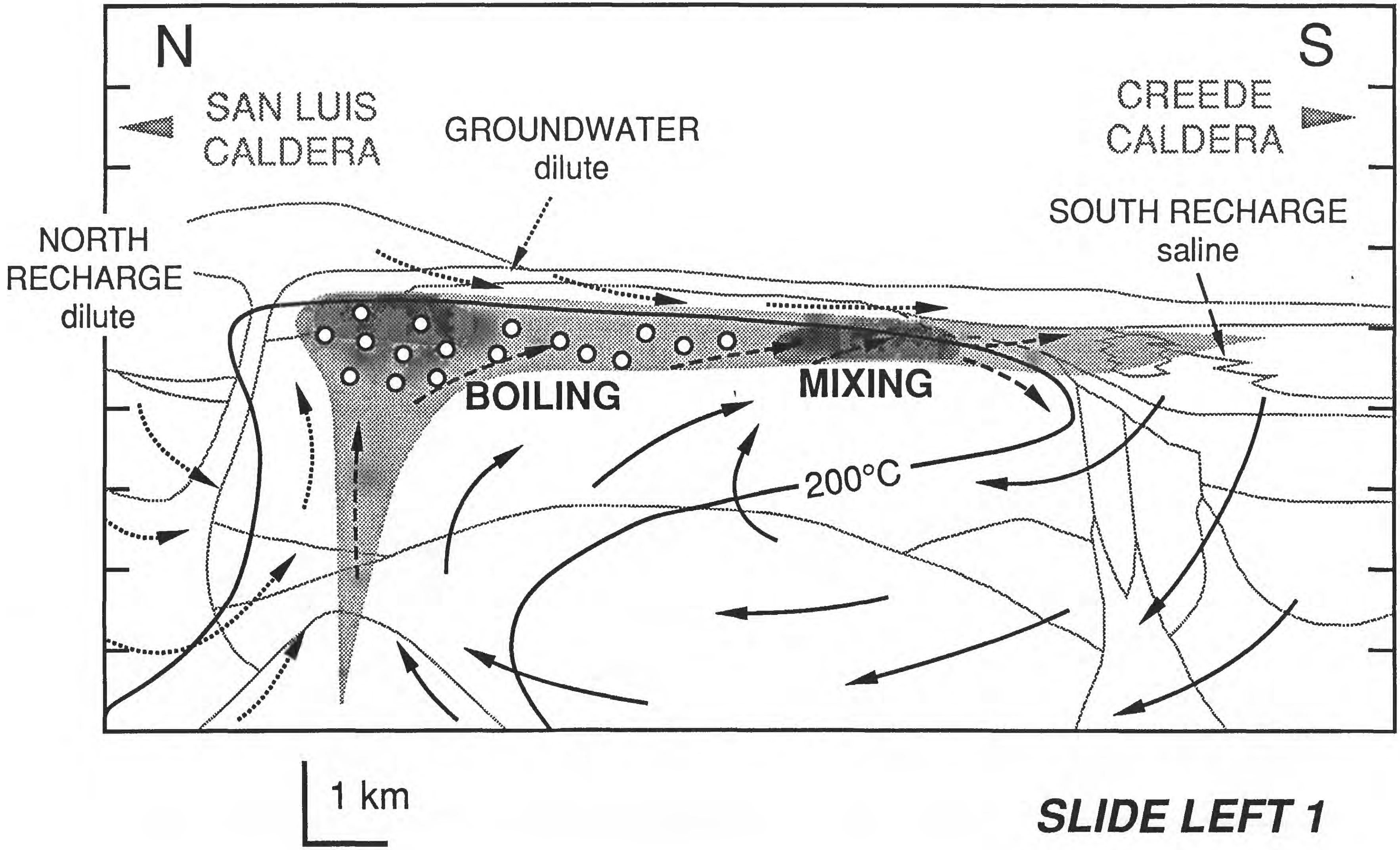
MAIN STAGE CREEDE SYSTEM HYDROLOGY



SLIDE LEFT 1

SLIDE RIGHT 1

MAIN STAGE CREEDE HYDROLOGY

SOUTHERN RECHARGE

-saline, isotopically heavy

NORTHERN RECHARGE

-dilute, isotopically light

ORE ZONE PROCESSES

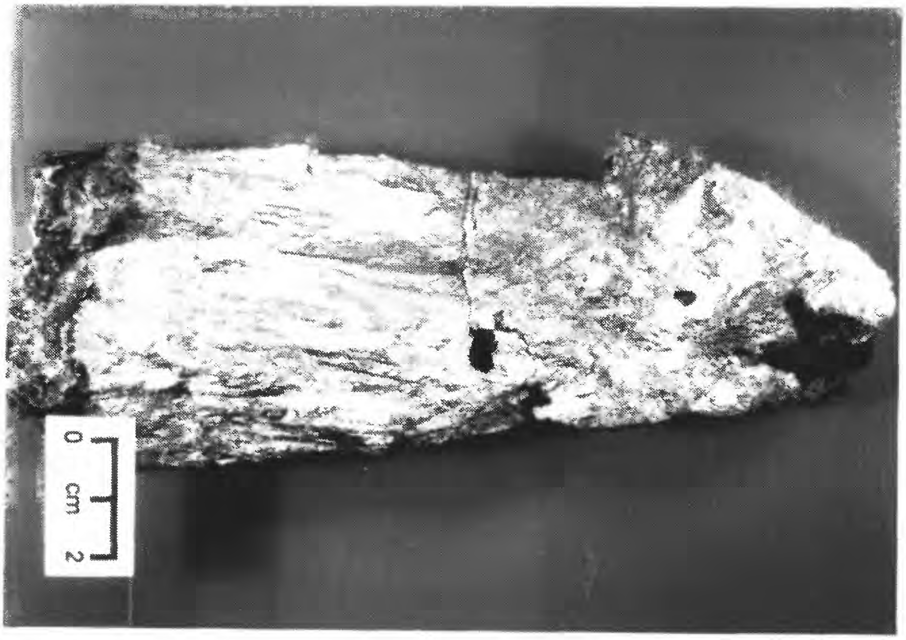
1) BOILING
   - in hotter parts of upwelling plume
   - volatile gaseous species → vapor phase

2) CONDENSATION OF VOLATILES
   - in overlying dilute groundwaters
   - creates moderately acid conditions

3) MIXING
   - of brines with overlying dilute groundwaters

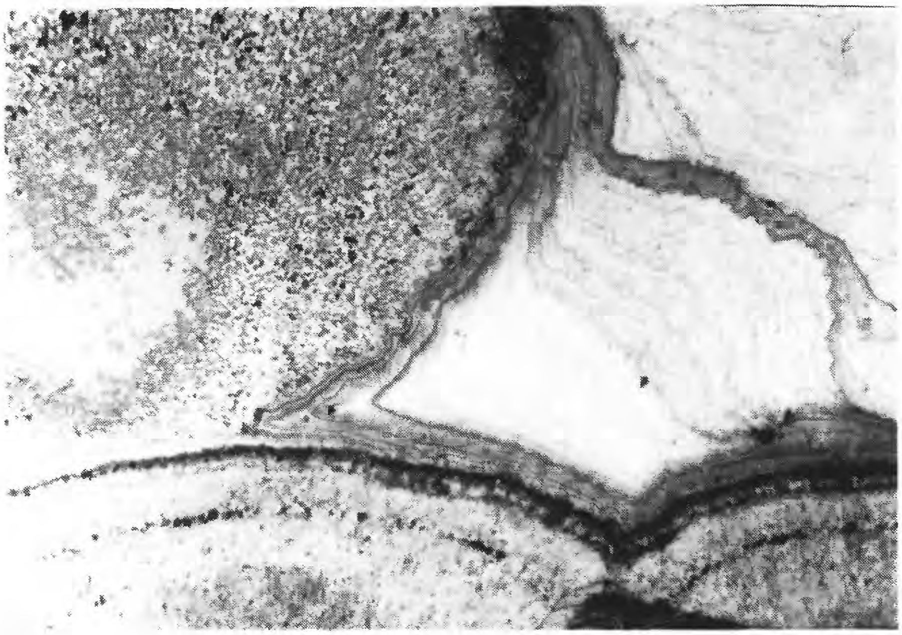
SLIDE LEFT 2

LATE-STAGE CREEDE BOTRYOIDAL PYRITE



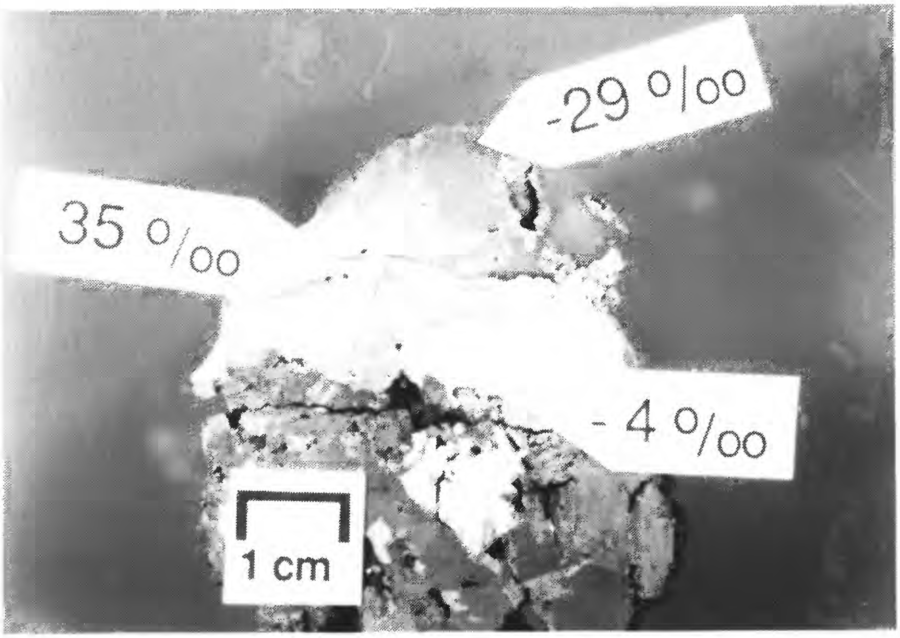
SLIDE RIGHT 2

PHOTOMICROGRAPH, CREEDE PYRITE

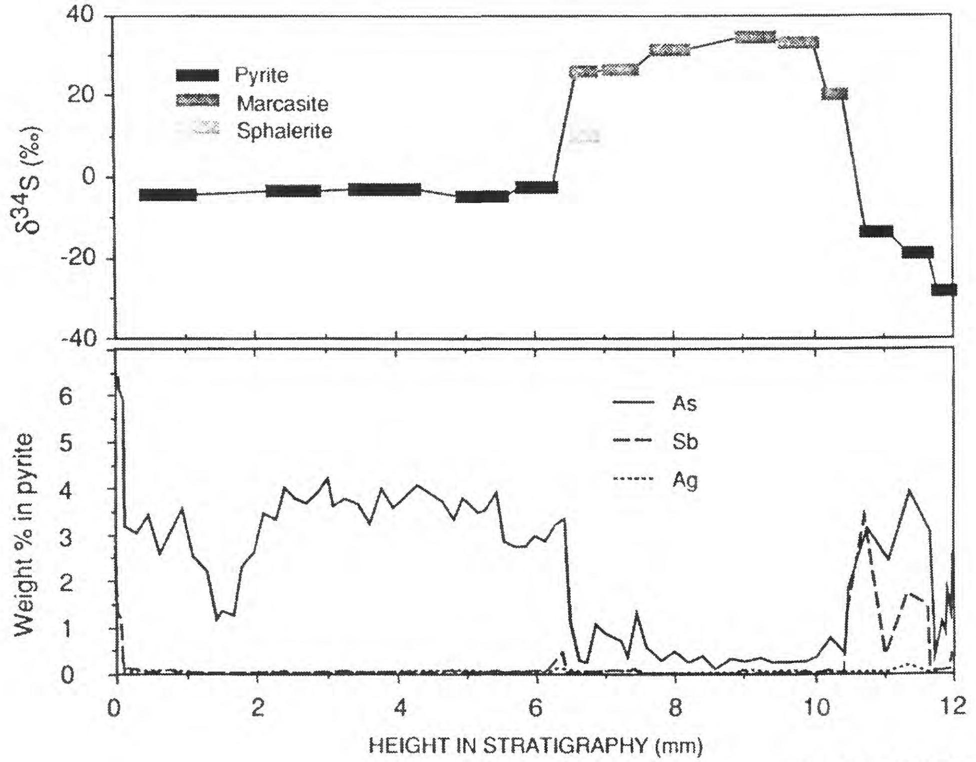


SLIDE LEFT 3

CREEDE PYRITE AND MARCASITE



SAMPLE MB-U, OH VEIN



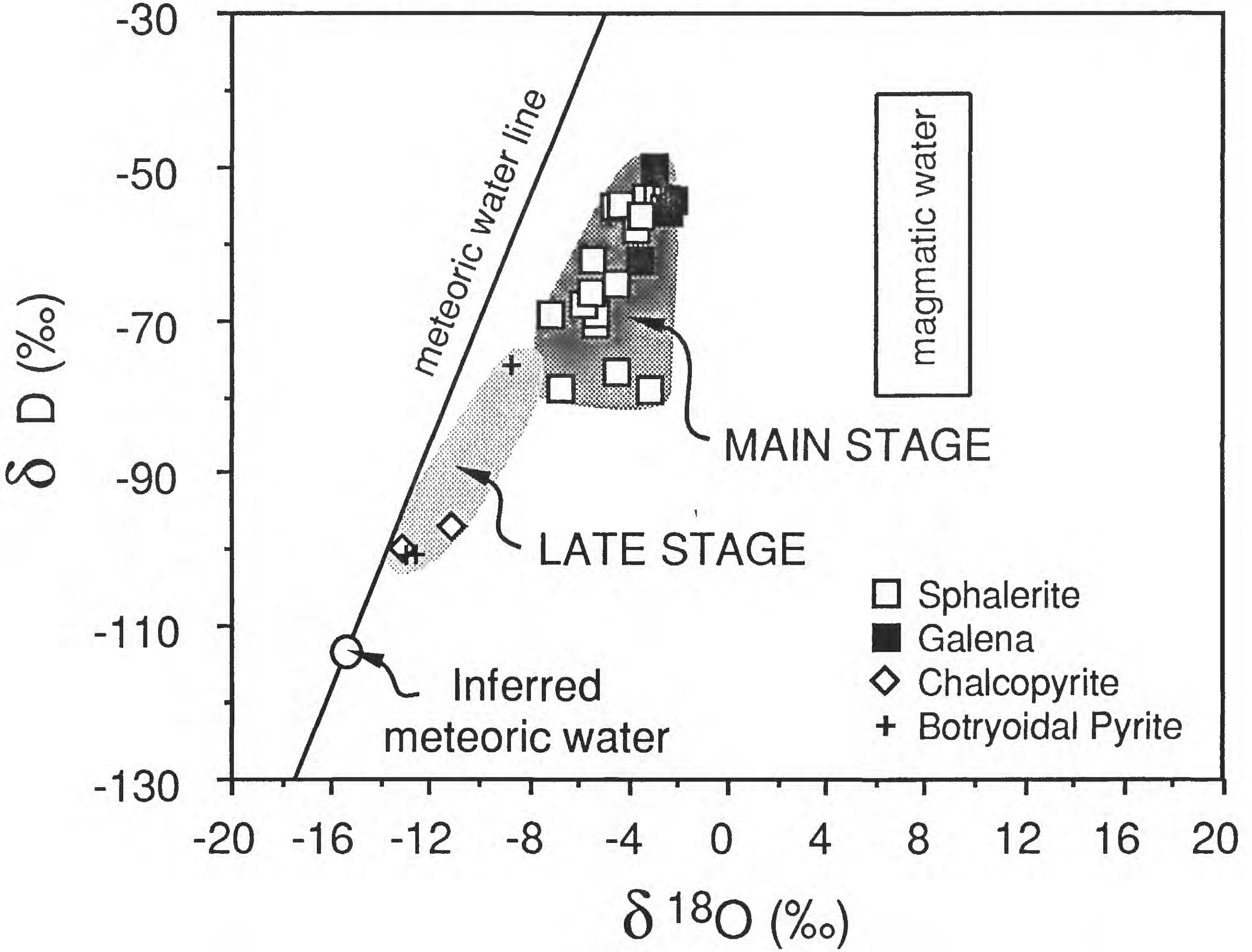
SLIDE RIGHT 3

SLIDE LEFT 4

LATE-STAGE CHEMICAL ENVIRONMENT

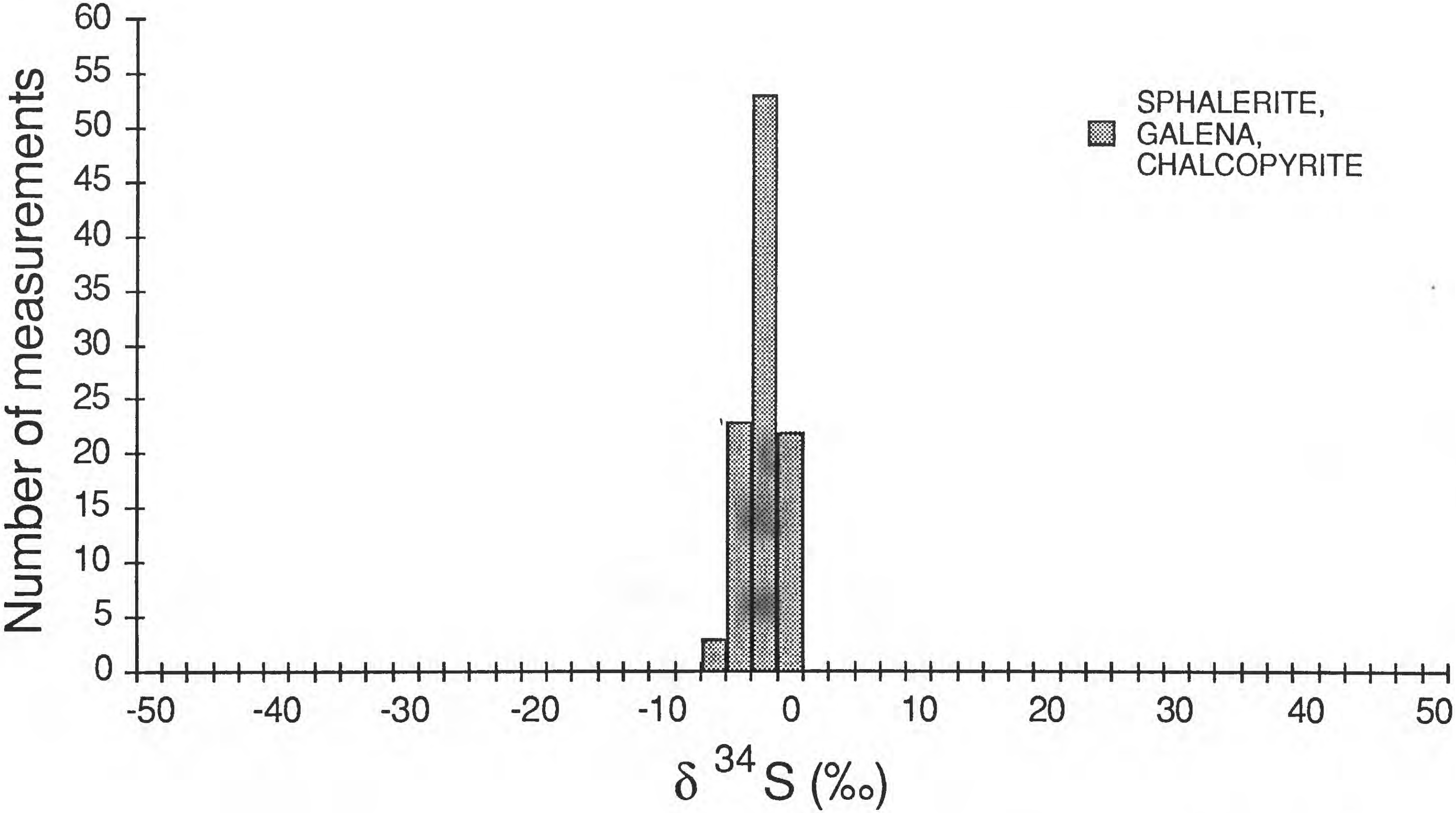
1. Temperature < 200°C
2. Moderately acid pH (~4.5 to 5, marcasite stable)
3. Moderately oxidizing conditions
4. Moderately sulfidizing conditions (famatinite stable)
5. "Mobil" epithermal elements (As, Sb, etc.) abundant

H - O ISOTOPIC COMPOSITIONS OF MAIN & LATE STAGE INCLUSION FLUIDS



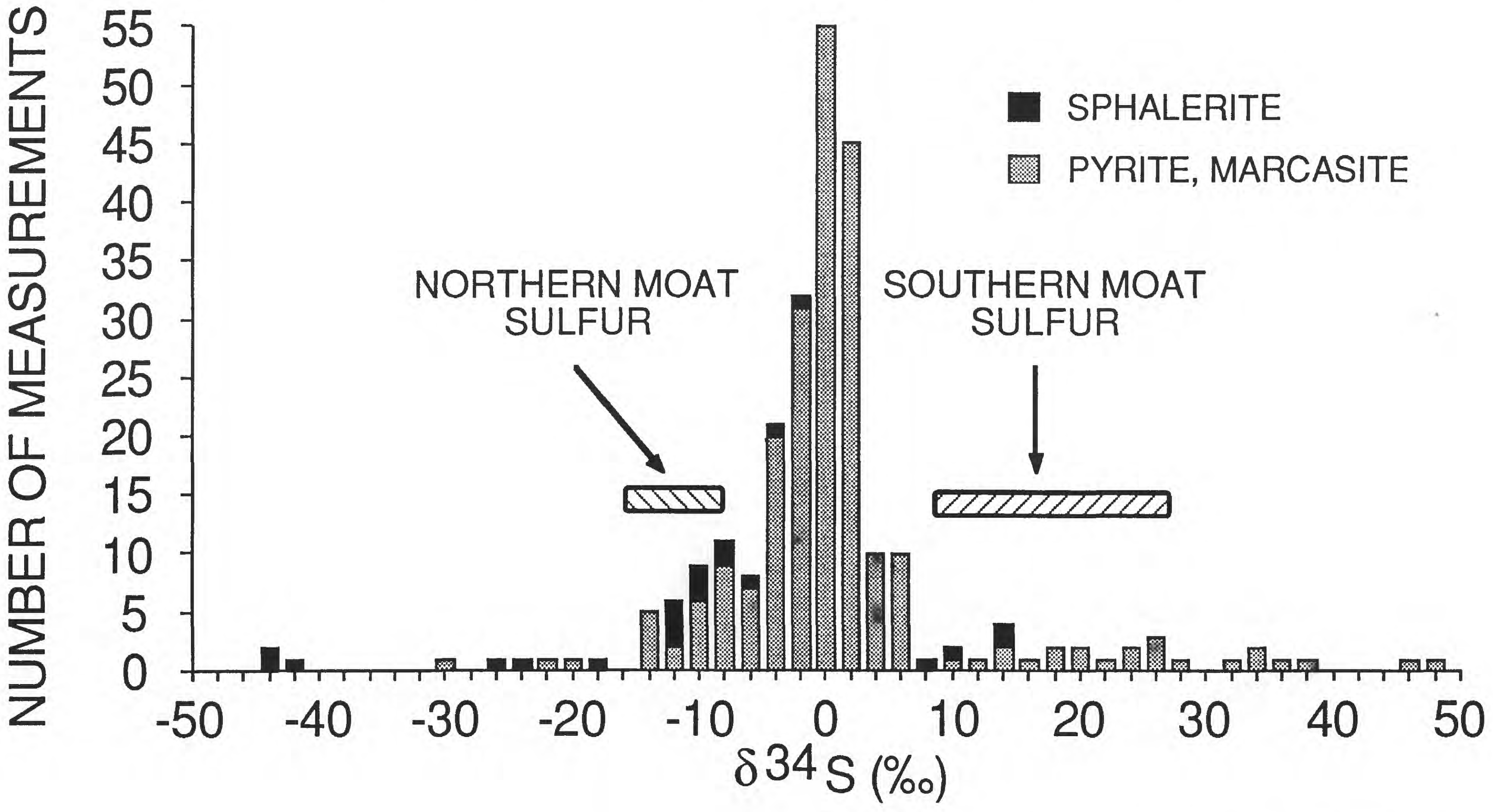
SLIDE LEFT 5

SULFUR ISOTOPE COMPOSITIONS OF MAIN-STAGE SULFIDES



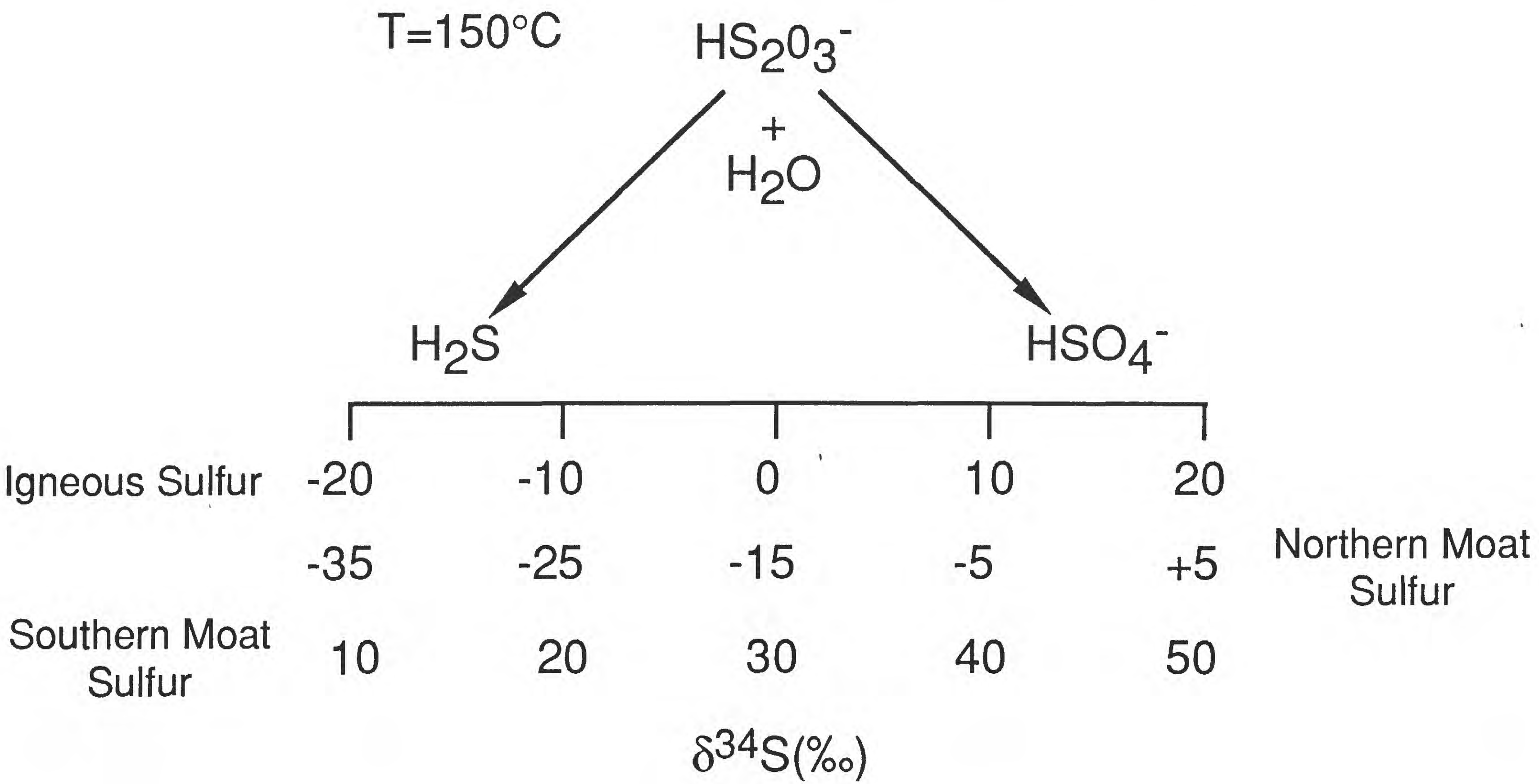
SLIDE LEFT 6

LATE-STAGE SULFUR ISOTOPES



SLIDE RIGHT 6

THIOSULFATE DISPROPORTIONATION



T=150°C

$HS_20_3^-$ + H_2O → H_2S + HSO_4^-

Igneous Sulfur	-20	-10	0	10	20	
	-35	-25	-15	-5	+5	Northern Moat Sulfur
Southern Moat Sulfur	10	20	30	40	50	

$\delta^{34}S$(‰)

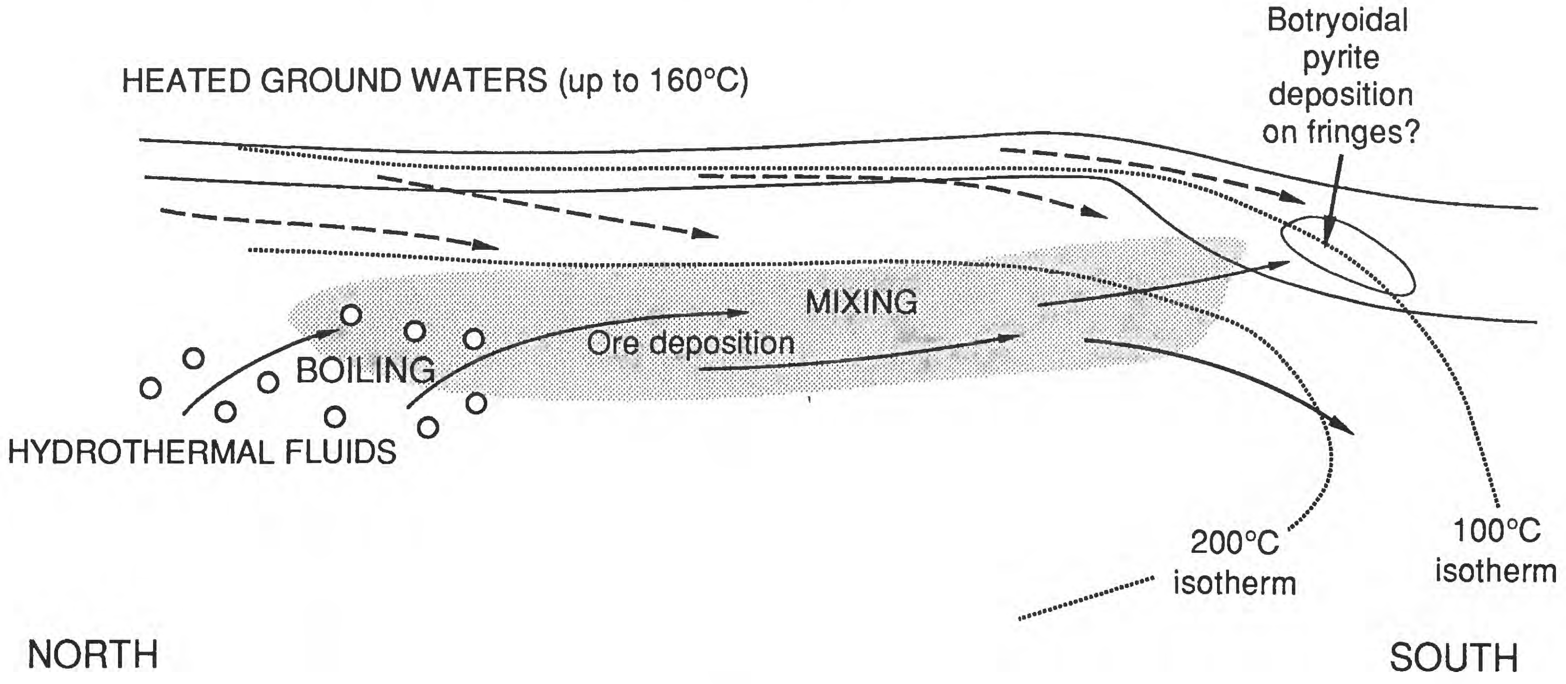
SLIDE LEFT 7

SLIDE RIGHT 7

Extreme $\delta^{34}S$ variations in late stage Creede sulfides may reflect the combined effects of:

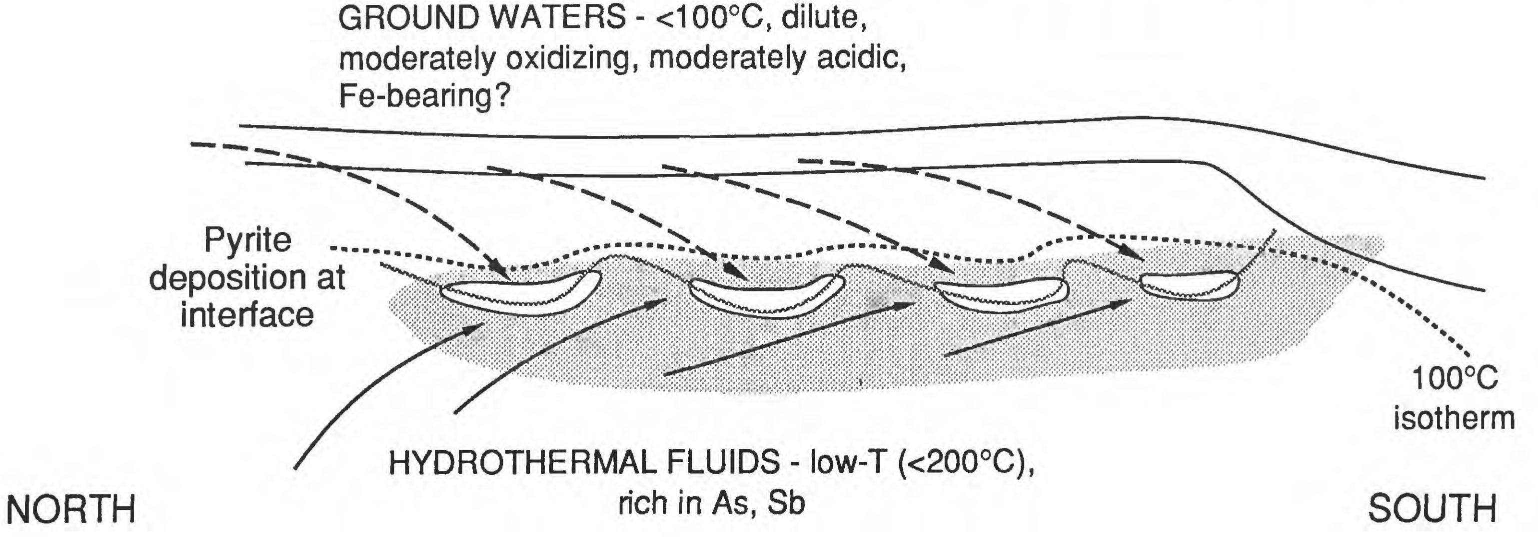
1) Increased input of sedimentary-derived sulfur over igneous sulfur.
2) Possible non-equilibrium reactions involving intermediate sulfur species, such as the disproportionation of thiosulfate.
3) Possible thermochemical reduction of sulfate by organic matter (T > ~120°C)
3) Possible biogenic activity (T < 110°C).

MAIN STAGE CREEDE ORE ZONE HYDROLOGY



SLIDE LEFT 8

LATE STAGE CREEDE ORE ZONE HYDROLOGY



GROUND WATERS - <100°C, dilute, moderately oxidizing, moderately acidic, Fe-bearing?

Pyrite deposition at interface

100°C isotherm

HYDROTHERMAL FLUIDS - low-T (<200°C), rich in As, Sb

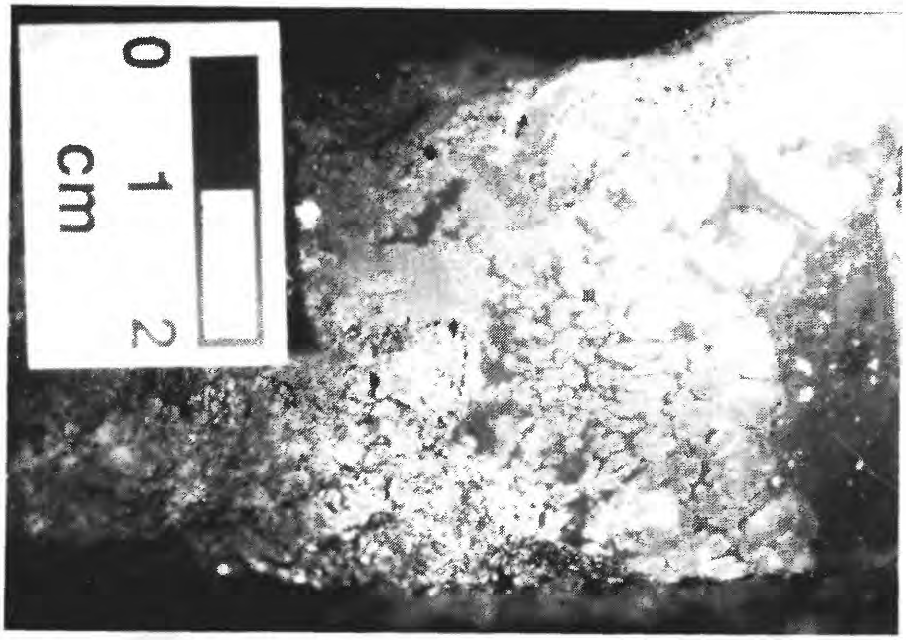
NORTH

SOUTH

SLIDE RIGHT 8

SLIDE LEFT 9

LAKE CITY MARCASITE, PYRITE, ALUNITE



SLIDE RIGHT 9

LAKE CITY, COLORADO

TYPE:	**Epithermal precious metal.**
MINERALOGY: (late)	**Marcasite, bot. pyrite, barite, chalcedony, alunite**
TRACE ELEM.: (in pyrite)	**As (up to 2 wt%)** **Sb (up to 1 wt%)** **Te (up to several wt%)**
$\delta^{34}S_{sulfide}$:	**Late: -11‰ to -14‰** **Main: -3‰ to -6‰**
REFERENCE:	**This study** **Slack, 1980;** **J. Slack, pers.comm.** **D. Bove, pers. comm.**

SLIDE LEFT 10

JULCANI PYRITE

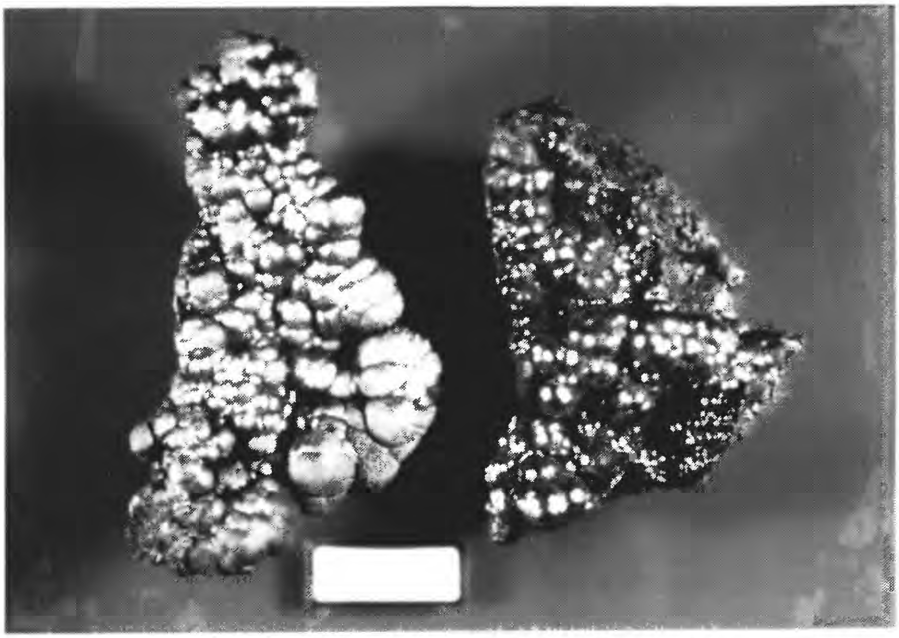
SLIDE RIGHT 10

JULCANI, PERU

TYPE:	Base metal lode.
MINERALOGY: (late)	Galena, marcasite, bot. pyrite, siderite
TRACE ELEM.: (in pyrite)	Sb (up to 3.3 wt%)* As (up to 4.9 wt%)*
$\delta^{34}S_{sulfide}$:	Late: +1‰ to +25‰ Main: -6‰ to +7‰
REFERENCE:	Deen et al., 1987 *J. Drexler, unpub. data

SLIDE LEFT 11

CERRO DE PASCO Pb-As-S GLASS



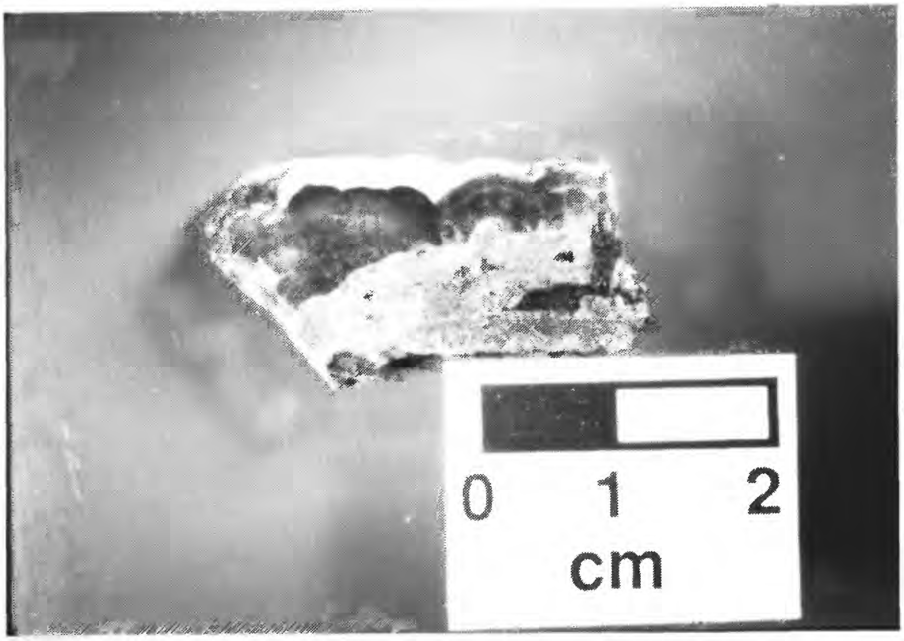
SLIDE RIGHT 11

CERRO de PASCO, PERU

TYPE:	Base metal lode.
MINERALOGY: (late)	Hydrothermal leaching, Pb-As-S glass, bot. sphalerite, pyrite, galena, realgar, hematite
TRACE ELEM.:	High As
$\delta^{34}S_{sulfide}$:	Late: -38‰ to -8‰ Main : 0‰ to +5‰
REFERENCE:	Petersen, 1965 Jensen, 1959 Lacy and Hosmer, 1956

SLIDE LEFT 12

SAN CRISTOBAL PYRITE



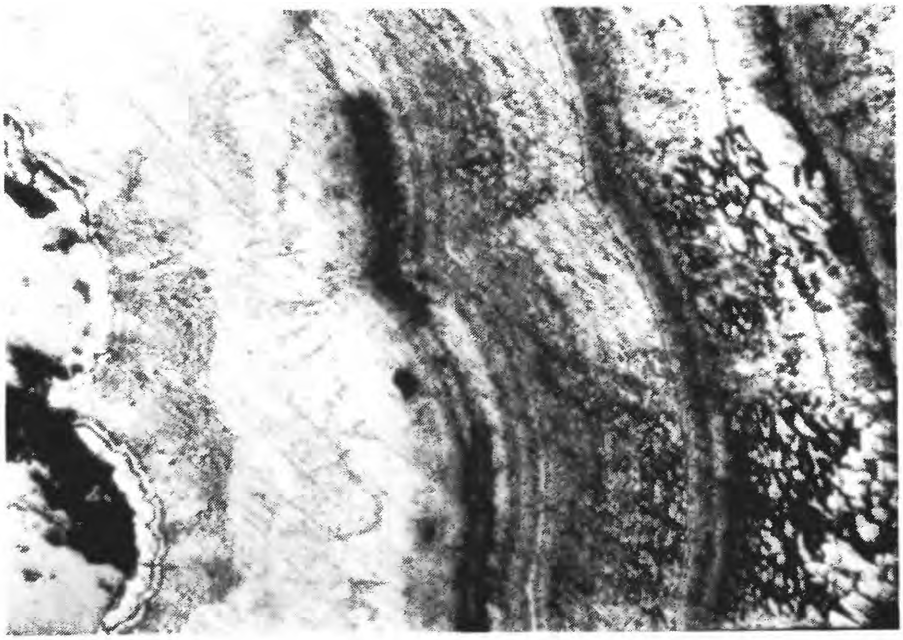
SLIDE RIGHT 12

SAN CRISTOBAL, PERU (CARAHUACRA)

TYPE:	Manto, related veins.
MINERALOGY: (late)	Mn-siderite, marcasite, bot. pyrite, bot. sphalerite, barite, magnetite
TRACE ELEM.: (in pyrite)	As (up to 1 wt%) Sb (up to 1 wt%)
$\delta^{34}S_{sulfide}$:	Late: -32‰ to +8‰ Main: +2‰ to +8‰*
REFERENCE:	This study *Bartlett, 1984

SLIDE LEFT 13

JACHYMA PYRITE



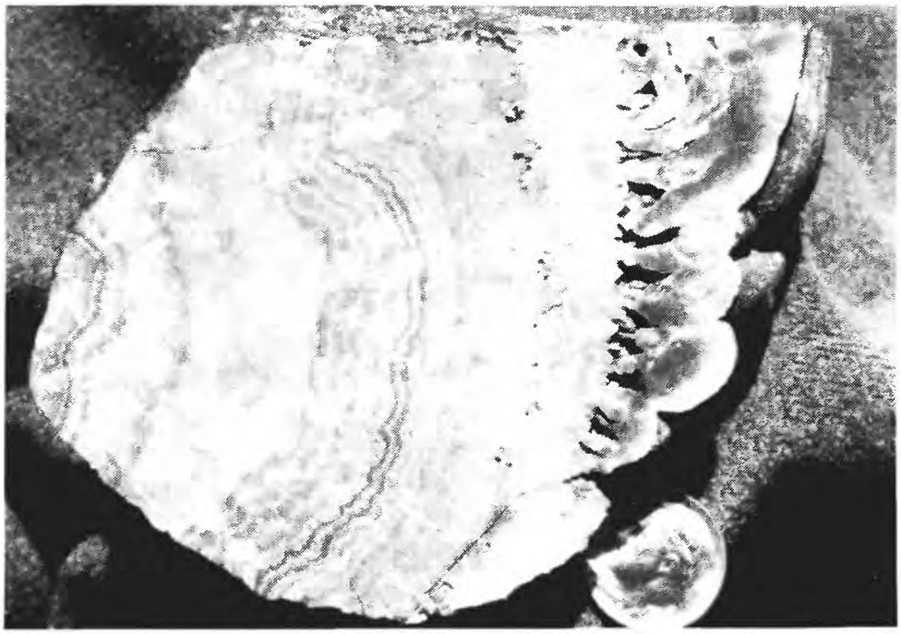
SLIDE RIGHT 13

Jáchyma, Czechoslovakia (Joachimstal)

TYPE:	Hydrothermal Ag-Co-Ni-Bi-U-As.
MINERALOGY: (late)	Calcite, bot. pyrite, galena, sphalerite, chalcopyrite, realgar
TRACE ELEM.: (in pyrite)	As (up to 8 wt%) Sb (up to 2 wt%)
$\delta^{34}S_{sulfide}$:	Late py: -20‰ to -24‰ Main: ?
REFERENCE:	This study Laznicka, 1985 (Paragenesis)

SLIDE LEFT 14

UPPER MISSISSIPPI VALLEY, MARCASITE COATING SPHALERITE



SLIDE RIGHT 14

UPPER MISSISSIPPI VALLEY

TYPE:	MVT
MINERALOGY:	Marcasite, barite, sphalerite, galena
TRACE ELEM.:	?
$\delta^{34}S_{sulfide}$:	Late: +5‰ to +25‰ Main : +9‰ to +18‰
REFERENCE:	McLimans, 1977

SLIDE LEFT 15

KAMCHATKA OOLITIC PYRITE

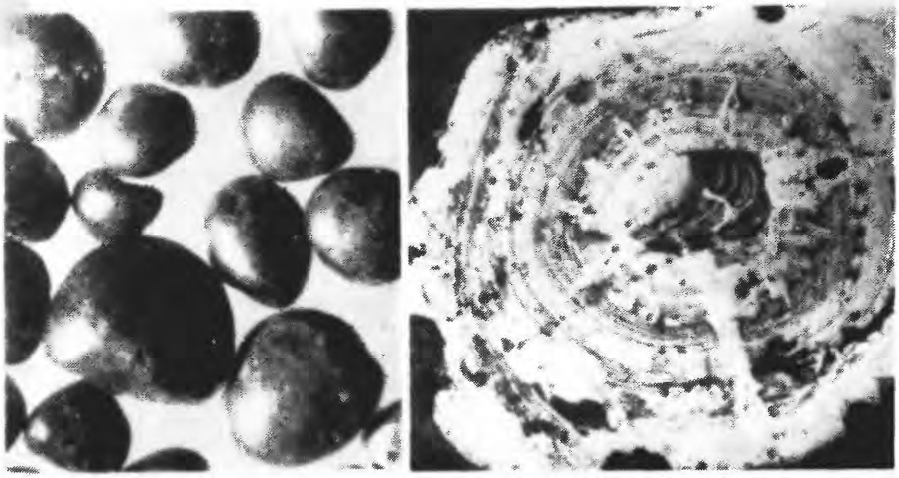


Fig. 5: Oolites of pyrite from Dvukhyurtochnye springs (a); magnification × 30. Internal structure of oolite (b): polished section, magnification × 375.

SLIDE RIGHT 15

KAMCHATKA, USSR

TYPE:	**Thermal springs.**
MINERALOGY:	**Oolitic pyrite, marcasite, cinnabar, metacinnabar, stibnite, etc.**
TRACE ELEM.: **(in pyrite)**	**"High As"** **"High Hg"**
$\delta^{34}S_{sulfide}$:	**Pyrite: -41‰ to +1‰** **Cinn : -10‰ to -2‰**
REFERENCE:	**Ozerova et al, 1971**

SLIDE LEFT 16

LATE-STAGE BOTRYOIDAL PYRITE/MARCASITE OCCURRENCES

TYPE	DEPOSIT
1. Epithermal	Creede, CO
	Bohemia, OR
	Lake City, CO
	Cartagena, Spain
2. Base Metal Lode	Julcani, Peru
	Quiruvilca, Peru
3. Manto	San Cristobal, Peru
4. Co-Ni-As-Ag-Bi Veins	Jáchyma, Czech.
5. Hydrothermal Uranium	Schwartzwalder, CO
6. Metamorphic Au	Mother Lode, CA
7. Hydrothermal Sn-W	Panasquiera, Port.
8. MVT	Upper Mississippi Valley

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CONCLUSIONS

Chemical variations in the same basic collapse process from deposit to deposit may be manifested by combinations of any or all of the following:

a) isotopically distinctive botryoidal pyrite, marcasite, ± sulfosalts, ± sphalerite;
b) alunite
c) isotopically heavy carbonates;
d) chalcedony;
e) barite;
f) hypogene leaching;
g) sulfide glasses

SLIDE LEFT 17

"SHALLOW" BOTRYOIDAL PYRITE/MARCASITE OCCURRENCES

TYPE	DEPOSIT
1. Thermal Springs	Golconda, NV
	Kamchatka, USSR
	Toscana, Italy
2. Hot Spring Au-Ag-Hg	McLaughlin, CA
	Delamar, ID
	Sulfur Bank, CA
3. Massive Sulfide	Kuroko deposits, Japan

SLIDE RIGHT 17

CONCLUSIONS

HOT SPRING DEPOSITS:

The occurrence of extreme sulfur isotope values in trace-element enriched pyrite and marcasite suggests that non-equilibrium sulfur chemistries may have been involved.

Further studies, currently underway, are needed to fully assess the potential roles of non-equilibrium sulfur chemistries in hot-spring mineralizing processes.