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Sedimentation in epithermal veins of the Bohemia mining district, Oregon, USA: Interpretations and significance

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Abstract. Open spaces in epithermal veins of the Bohemia mining district, Oregon, USA, filled with sediments during hydrothermal activity. These sediments consist mainly of chalcedony, rock fragments, and vein quartz fragments. In addition, hematite is deposited during stage three of the vein development. Observed sedimentary features include draping laminae, erosion surfaces, slumping, and graded bedding. Such sediments can be used for reconstruction of the original orientation of vein systems, because the sediment laminae are initially deposited horizontally. Vein sediments record variations in fluid flow due to selfsealing, fracturing, and cessation of hydrothermal activity. Investigation of vein sediments therefore provides an additional tool to unravel the geologic history of epithermal systems. The chalcedonic vein sediments record large temperature drops and highly silica supersaturated waters, probably due to fracturing and pressure release. Hematitic vein sediments indicate sulfide deficient hydrothermal fluids.

Introduction

The Bohemia mining district is located in the Cascade Range (Fig. 1), 70 kilometers southeast of Eugene, Oregon. Gold was first discovered in the Bohemia district in 1858 and most of the mining activity occurred in the period from 1892 to 1942, when government orders brought a halt to all gold mining. After 1945 sporadic mining occurred until 1957. Since then only exploration and prospecting has taken place in the Bohemia district. The Bohemia district was the most productive mining district in the Western Cascades of Oregon (Brooks and Ramp, 1968). The epithermal veins of the district were mined principally for gold, however, in later stages of mining, silver, copper, lead, and zinc were recovered as well.

Detailed studies of areal geology and of vein mineralization in the Bohemia district were undertaken by Lutton (1962) and most recently by Katsura (1986). Both authors report vein sediments to be a common feature of the epithermal veins of the district. Even though we have observed vein sediments in epithermal prospects in Idaho and eastern Oregon, other documented occurrences of sediments in epithermal vein deposits are sparse. Barton et al. (1971) described settling of hematite flakes onto sphalerite surfaces in Creede, Colorado. Kostelka and Petrascheck (1967) and Klau and Mostler (1983) describe internal sediments from karst cavities and fractures in Alpine Type Pb-Zn deposits. Kendall (1960) described sediment fillings in vugs of Mississippi Valley Type ore deposits. However, Mississippi Valley Type deposits and Alpine Type Pb-Zn deposits have a different genesis from epithermal vein deposits, and should therefore not be directly compared with them.

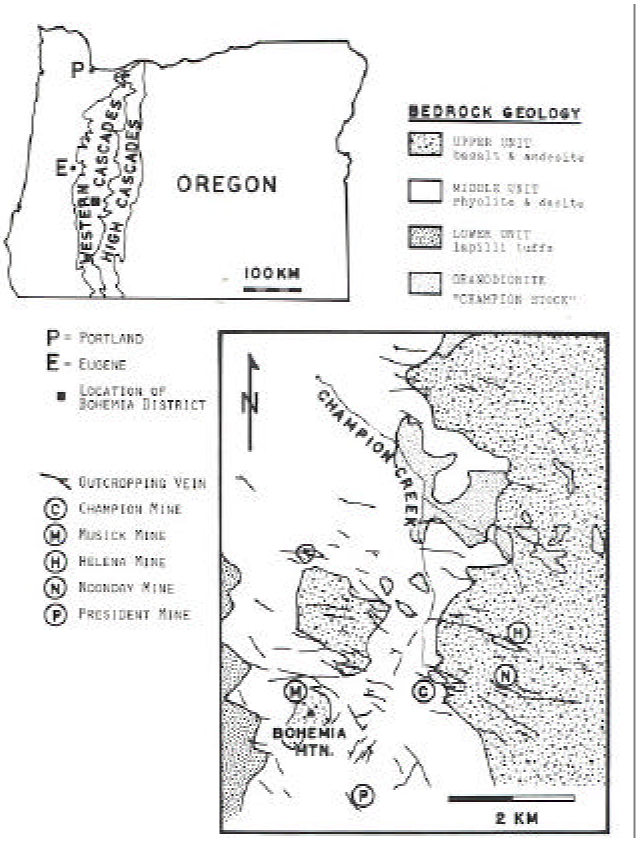


Fig. 1. Location map. Shows location of Bohemia district (black square) within the Western Cascades province, and in an enlarged map (after Callaghan and Buddington, 1938) the vein pattern and bedrock geology of the Bohemia district with locations of major mines. The lithologic units on the map correspond to the units described in the introduction to this paper

The observations that are presented in this report constitute a detailed description of vein sedimentation in epithermal deposits.

Regional geology

The Cascade Range is the product of arc volcanism that has been active since Eocene times (McBirney et al., 1974; Power, 1985). In Oregon, the Cascade Range has been subdivided into two belts of volcanic rocks, the Western Cascades of Eocene to Pliocene age and the High Cascades of Pliocene to recent age (Peck et al., 1964; Priest and Vogt, 1983). The Western Cascades consist of flows, pyroclastics, and volcanoclastic sediments that were deposited from numerous volcanic centers (Peck et al., 1964). Minor folding of the Western Cascades, along NE-trending fold axes, occurred during several periods in the late Eocene and late Miocene (Feck et al., 1964). The High Cascades, consisting mainly of basaltic to andesitic flows and of strato-volcano complexes, fill a N-S trending graben that developed in older volcanic rocks (Priest and Vogt, 1983).

An active volcanic center existed in the Bohemia area during the Oligocene to early Miocene (Peck, 1960; Lutton, 1962). Interstratified flows and tuffs of basaltic to rhyolitic composition have been mapped and divided into three units (Fig. 1) by Lutton (1962). The lower unit consists of over 300 m of massive dacitic to rhyolitic lapilli tuffs with locally intercalated tuffaceous sandstones and lacustrine shales. The intermediate unit (approximately 450 m thick) is characterized by dacites and rhyolitic dome complexes with onlapping flows and pyroclastics that fill erosional paleotopographic features in the massive tuffs of the lower unit. The upper unit (approximately 250 m thick) consists predominantly of basalt and andesite flows with minor dacite flows and intercalated lapilli tuffs. The granodioritic Champion Stock and related plugs and dikes crosscut all volcanic units (Fig. 1). Power et al. (1981) determined an age of 21.7 m.y. for the Champion Stock. Crosscutting relationships show that the epithermal veins of the Bohemia district postdate the Champion Stock and are therefore younger than the associated volcanic and intrusive rocks.

Vein mineralization

Veins in the Bohemia district fill open fissures that generally dip 60-70 degrees and strike W-NW. Crustification banding of sphalerite, galena, chalcopyrite and quartz, multiple stages of brecciation, comb quartz, and fine grained chalcedonic vein sediments are common features in the veins. A range of average fluid inclusion homogenization temperatures of 240-350 degrees Celsius have been determined by Istas (1983) in vein quartz from several mines of the Bohemia district.

The generalized paragenetic sequences of minerals and textural features shown in Fig. 2 (Katsura, 1986) are based on detailed geologic mapping of the Champion mine and on study of crosscutting relationships in hand specimens. Paragenetic sequences in other mines of the district may differ in detail from that of the Champion mine, but generally they are similar (Lutton, 1962; Katsura, 1986).

Stage 1 mineralization (Fig. 2) occurs in narrow veins and is characterized by quartz-chlorite veins and breccias. Chlorite is either finely disseminated in quartz (causing pale green color of quartz) or it forms crustified bands of coarse platy crystals (0.1-1 mm in size).

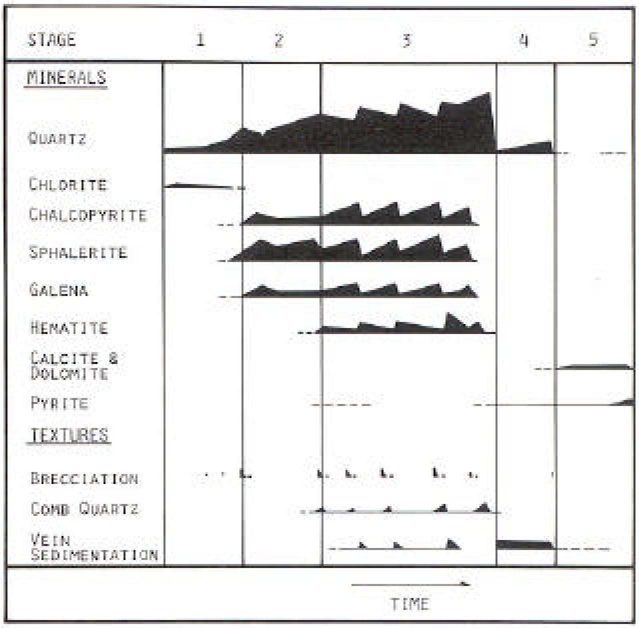


Fig. 2. Generalized time sequence of minerals, brecciation events, and vein sediments in the Champion mine of the Bohemia district. The height of blackened areas indicates relative abundance of minerals or features

Stage 2 mineralization exhibits crustification banding of sphalerite, chalcopyrite, galena and clear to milky quartz. In many places stage 2 mineralization occurs in the same fissures as stage 1 mineralization and is superimposed on it.

Stage 3 mineralization is characterized by fine-grained, purple-red hematite. Abundant comb quartz and large open vugs (as much as 0.5 m in size) indicate that stage 3 mineralization occurred in wide open fissures. Episodic brecciation and reopening of fissures is well documented (Lutton, 1962; Katsura, 1986) and affected mainly the contact zone between hanging wall and vein. Locally, spectacular vein breccias are developed, but generally the earlier-deposited mineralization remained unaffected by later brecciation (Katsura, 1986). In most places the growth of comb quartz took place after brecciation and was followed by sedimentation of a mixture of chalcedonic quartz and fine grained hematite in open spaces. In the time intervals between brecciation events, sulfides in crustified bands and quartz, commonly as comb quartz, were deposited. Gold deposition in the Champion vein occurred mainly during stage 3.

Stage 4 mineralization consists of gray to black, finely laminated chalcedonic vein sediments that fill vugs and open spaces in breccias. Color variations of chalcedony laminae are caused by admixed fine grained pyrite and clay. XRD studies showed the clay to be well crystallized kaolinite.

Stage 5 mineralization is characterized by calcite, dolomite, and fibrous pyrite. The carbonates occur in veins, as breccia cement, and together with pyrite as encrustations of earlier mineralization stages.

Sedimentary features

In the context of this study we consider as vein sediments that portion of vein fillings that was deposited in open spaces as particulate matter. The most common feature of the vein sediments is fine parallel lamination (Fig. 3). Most of the laminae are between 0.2 and 3 mm thick and can be distinguished because of subtle variations in color or grain size. In places, laminae of chalcedonic quartz alternate with detrital laminae, consisting of sand to silt-sized rock fragments, vein quartz fragments, and sulfide minerals (Fig. 4). The chalcedonic laminae consist of a mosaic of fine crystalline quartz. However, these laminae may have originally consisted of amorphous silica sediment, because Lutton (1962) observed "an abundance of small colloform spheres enclosing patches of submicroscopic inclusions" in some specimens. The original amorphous silica of chalcedonic laminae has recrystallized to quartz, and in most places the spherular texture has been obliterated during recrystallization.

Sediment laminae tend to drape over bottom irregularities and follow the contours of depressions (Figs. 5, 6). This feature is particularly visible in the lower portions of vein sediment packages. Laminae thin as they pass over positive topographic features and thicken in the intervening throughs (Fig. 3). Therefore, towards the top of a sediment package the laminations become increasingly smooth and horizontal. The tops of vein fill sediment packages (if exposed) usually show an even to undulose surface. Lamina sets that fill topographic depressions are usually slightly concave upwards (Figs. 5, 6).

In places thicker laminae (as much as 15 mm thick) were observed. These laminae contain coarse detrital material (rock fragments, vein quartz fragments, 0.1-4 mm grain size) and show normal grading (Fig. 7). In some thicker packages (10 cm or more in thickness) of vein sediment, internal erosion surfaces were observed that separate successive episodes of vein sedimentation (Fig. 3). Vein sediment that drapes over relatively steep slopes (slope angles of 30 degrees or more) may show slump structures (Fig. 3).

Interpretation of sedimentary features

Mineralization in the Bohemia district is of Miocene age (Power et al., 1981). Bedding planes of vein sediments are more or less horizontal and record the orientation of a horizontal plane relative to the vein at the time of vein formation (Fig. 8). Kendall (1960) used the orientation of internal sediments in vugs of Mississippi Valley Type deposits to show that mineralization occurred prior to tilting of the host rocks. Analogously one may conclude that the host rocks of the Bohemia veins have undergone little tilting and deformation since the Miocene mineralizing event. Concavity of vein sediment laminae and the draping of vein sediments over the bottom topography of sediment filled cavities can be used to decide whether a vein and its associated host rocks were overturned during tectonic deformation.

Draping laminae of vein sediment indicate gravitational settling of particulate matter (floccules of amorphous silica, rock fragments etc.) from suspension in a slowly moving or stagnant fluid. This type of vein sedimentation probably occurs in protected areas (pockets) of the vein system where relatively small flow velocities prevail. Thus, the vein sediments can be considered geopetal fabrics, analogous to fossil spirit levels in normal sedimentary rocks.

Alternation of laminae of chalcedonic quartz (recrystallized from originally amorphous silica floccules; Henley and Brown, 1985; Fournier, 1985 a), with the coarser grained detrital laminae (Fig.4) may indicate alternating periods of current flow when transport of detrital material and deposition of detrital laminae occurred and relative quiescence when silica floccules were deposited. This is analogous to interpretations of interbedded mud and sand in normal sediments (Reineck and Singh, 1980, p. 113-125). Erosion surfaces, such as shown in Fig. 3 further indicate that prolonged conditions of relative quiescence that existed locally (as indicated by accumulation of fine laminated chalcedonic quartz), were at times interrupted by episodes of strong fluid flow.

1n normal sedimentary environments, flow velocities can be estimated from the grain size of the accumulating sediments (Sundborg, 1967). In contrast to the essentially horizontal fluid flow in normal sedimentary environments, fluid flow along faults and fissures of recent hydrothermal systems has a strong vertical upward component (Elder, 1981; Hedenquist, 1983). Barton et al. (1971) determined the relationship between settling velocity and diameter of hematite flakes, in order to estimate the vertical component of fluid flow in Creede, Colorado. In the Champion vein, complex fissure geometry and obstacles along the fluid pathway would have caused oblique and even horizontal flow locally, and would most

Fig.3. Hand specimen of chalcedonic vein sediment. Important features are highlighted in line drawing to the right. A=Thick chalcedonic lamina (oblique line pattern) that thins over topographic high. B=slump features. Arrow points to contorted laminae above. C=Erosional surface. qu=projections of encrusted quartz crystals into cavity. qul=draping of laminae over these obstacles. The scale bar in this and in all following figures represents 1 cm. In figures 3 to 8 the tops of sample photographs represent the tops of oriented samples

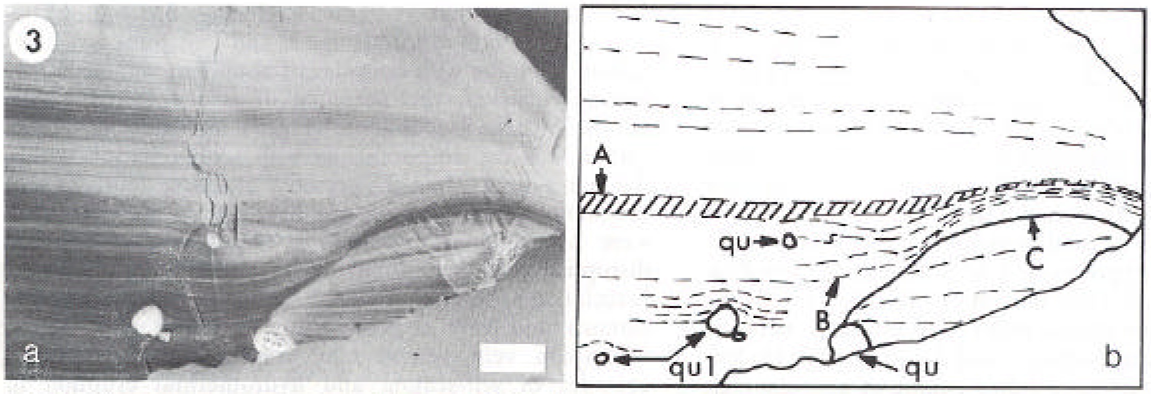
Fig. 4. Detail of interlaminated vein sediment from Fig. 8. c=chalcedonic lamina. d=detrital lamina

Fig. 5. Draping of vein sediment laminae over bottom irregularities

Fig. 6. Concave laminae in a sediment filled vug

Fig. 7. Graded laminae of chalcedonic-hematitic vein sediment. Fining upwards in each lamina indicated by arrows

Fig. 8. Sample from steeply dipping vein with filling of vein sediment. Note that vein sediment laminae are horizontal. Line drawing of sample shows vein sediment indicated by S, and crustification banding indicated by C. In the upper half of the sediment filling detritus (stipple pattern in line drawing) is more abundant on the right (footwall) side and interfingers with chalcedonic laminae on the left. It appears that detrital material slid down on the footwall side of the fissure and spread out to the left over earlier sediment laminae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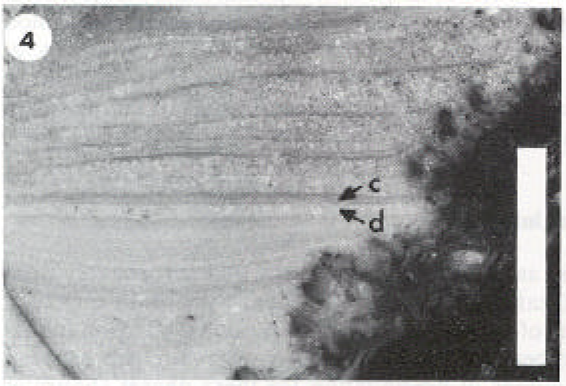
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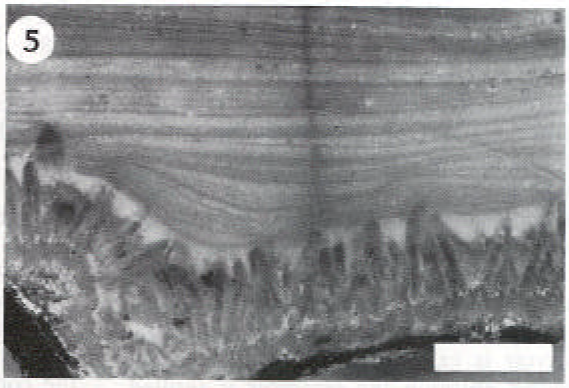
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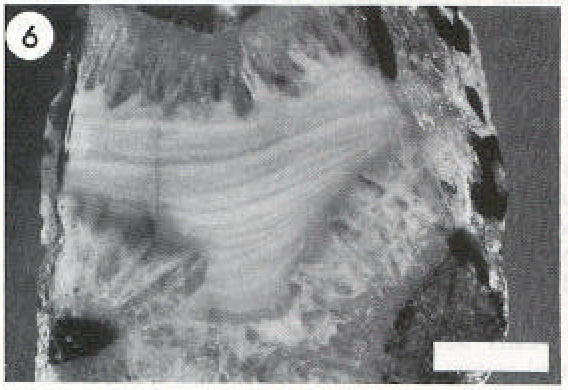
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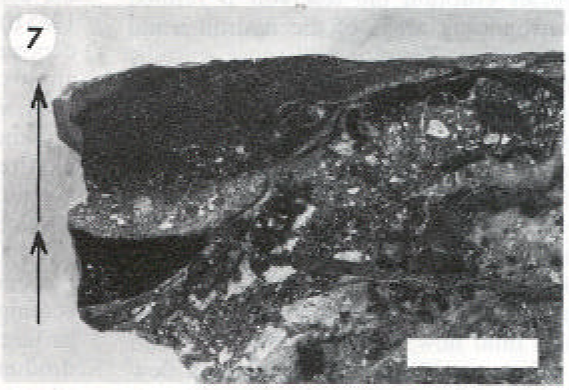
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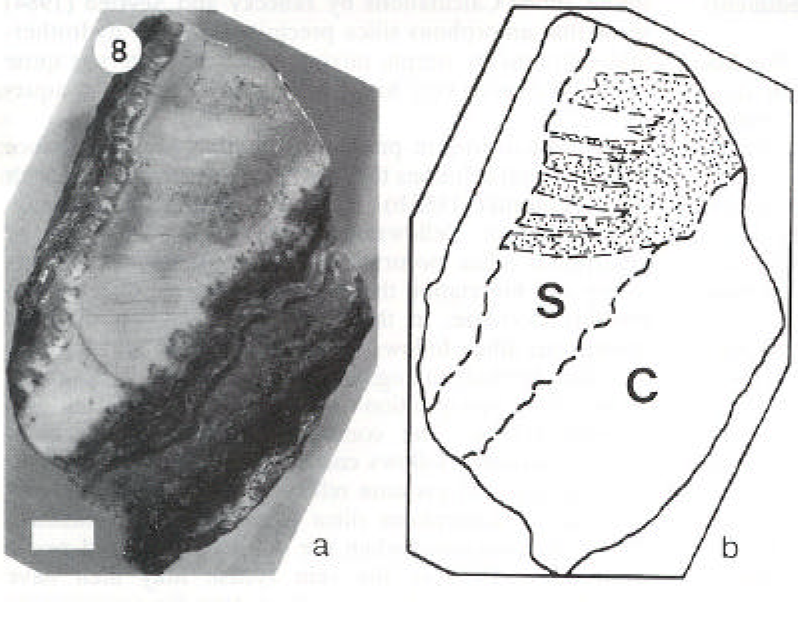
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likely have caused turbulent flow through the vein system. In such a case an approach via Stoke's Law cannot be applied to calculate settling velocities of sedimentary particles, and it is practically impossible to conclude possible flow velocities from particle sizes. The only inference to flow velocities that can be made is that stagnant conditions or small flow velocities must have prevailed at sites where the generally fine grained vein sediments accumulated.

In recent hydrothermal systems, such as Yellowstone, U.S.A., Steamboat Springs, U.S.A., Broadlands, New Zealand, boiling occurs when the vapor pressure exceeds the hydrostatic pressure (Ellis, 1979). The interplay between self-sealing of channels (Facca and Tonani, 1967; Hedenquist and Henley, 1985) and the opening of new channels during boiling and brecciation causes repeated changes of fluid flow patterns during the history of a hydrothermal system (Elder, 1981). Hydraulic brecciation during hydrothermal eruptions opens new fluid conduits in the hydrothermal system and opens new discharge points (eruption craters) to the surface (Hedenquist 1983). In that part of a fissure where these new conduits are created, fluid flow will increase relative to flow before brecciation, and consequently the flow pattern in the fissure will adjust to the new conditions. Geysers in modern hydrothermal system are a result of episodic boiling. Water is forced upwards through conduits at high velocities until the geyser's water reservoir is exhausted or cooled (Goguel 1976). After the geyser eruption the reservoir is refilled with water from surrounding areas of the hydrothermal system. Thus, episodic geyser eruption will cause episodic flow or flow variations in areas surrounding the geyser.

In the veins of the Bohemia district boiling is suggested by crustification banding of sulfides and by multi-stage vein breccias. Even though crustification banding and brecciation are only equivocal and empirical indicators of boiling, by analogy with recent hydrothermal systems it is quite likely that the fluid flow pattern in the veins of the Bohemia district changed repeatedly and that boiling was a common but episodic process. Under such conditions strong fluctuations of fluid flow, as well as the formation of partially sealed off areas with generally slow fluid flow (allowing accumulation of fine laminated vein sediment) should have been common.

Internal sediments of hydrothermal veins in the Bohemia district record a history of strong surges of fluid flow that alternated with periods of quiescence. Temporal variations of fluid flow are recorded on a fine scale by the individual laminae within packages of vein sediment (Figs. 3, 4, 5), and also on a larger scale by the erosion surfaces within packages of vein sediments (Fig. 3). These erosion surfaces may indicate infrequent events of unusually strong fluid flow, whereas the individual laminae indicate minor (much more frequent) pulsations.

In the Champion vein of the Bohemia district two distinct episodes of abundant vein sedimentation were recognized by Katsura (1986; see also Fig. 2). Vein sedimentation during stage 3 occurred repeatedly in the time intervals between brecciation events (see Fig. 2). In many places the growth of comb quartz preceded deposition of vein sediments (Figs. 5 and 6), but in some locations sedimentation followed brecciation immediately (Fig. 7). Most of the hematitic vein sediments were deposited in open spaces of breccias after comb quartz development had cemented the breccia and had restricted fluid flow.

Figure 2 shows that hydraulic fracturing (brecciation) occurred repeatedly during stage 3, and that pulses of brecciation alternate with episodes of abundant vein sedimentation. However, the presence of interstratified coarse debris in stage 3 sediments (Fig. 7) indicates that brecciation was contemporaneous with sedimentation within the vein system. Thus, the presence of coarse debris in vein sediments probably indicates that pulses of brecciation were not singular catastrophic events, but rather that disruptive activity gradually declined after an initial strong brecciation. The alternation of hydraulic fracturing (brecciation) and vein sedimentation during stage 3 in the Champion vein system may corespond to alternating episodes of self-sealing and hydrothermal eruption in recent geothermal systems (Elder 1981; Berger and Eimon 1983; Hedenquist and Henley 1985). The sediments in stage 4 of the vein evolution are widespread throughout the vein, and probably indicate gradual cessation of hydrothermal activity.

Chemical implications

The close association of chalcedonic quartz (probably from recrystalization of amorphous silica) with comb quartz in the veins of the Bohemia district poses an interpretational problem because there is a large temperature gap between the conditions of precipitation for these phases (Fournier 1985 b). Precipitation of amorphous silica following quartz deposition (comb quartz) requires a temperature drop of approximately 150 degrees Celsius (Janecky and Seyfried 1984; Fournier 1985 b). The repeated alternation of chalcedonic sediment and comb quartz in the Champion vein requires therefore repeated temperature drops of above magnitude. The problem is, how these temperature drops are to be achieved.

If brecciation would allow cool surface waters to descend and to mix with the hot hydrothermal waters, cooling would be achieved. However, besides cooling, the surface waters would dilute the hot, silica-enriched hydrothermal waters, precluding the precipitation of amorphous silica. Calculations by Janecky and Seyried (1984) show that amorphous silica precipitation from hydrothermal solutions by simple mixing with cold waters is quite unlikely, even at very high initial concentrations of aqueous silica.

A sudden drop in pressure is another way to produce hydrothermal solutions that are highly supersaturated with silica (Fournier 1985 b). Keith and Muffler (1978) suggested that at Yellowstone Park, USA, deposition of amorphous silica occurred as the consequence of fracturing and brecciation that was accompanied by a sudden pressure decrease. In the Champion vein deposition of amorphous silica follows brecciation events, and it could therefore be that, analogously to Yellowstone Park, amorphous silica precipitation was caused by fracturing and pressure release. The common observation that chalcedonic sediment follows comb quartz may indicate that immediately after pressure release, temperatures were still too high for amorphous silica to precipitate. Conductive cooling that occurred when the hot waters entered newly fractured portions of the vein system may then have caused a large enough temperature drop for precipitation of abundant amorphous silica.

Another interpretational problem in the Champion vein is posed by the precipitation of hematite in close proximity to sulfide minerals, a circumstance requiring either that the hydrothermal fluids were oxidizing, or that they were sulfide deficient. In the Champion vein replacement of chalcopyrite by hematite indicates that the fluids were sulfide deficient. In addition, no high-sulfur copper minerals, such as bornite, chalcocite, and covellite, were observed. If there had been sufficient sulfur in the fluids one should expect to see replacement of chalcopyrite by bornite and pyrite under sulfur addition. Because this has not been observed in the Champion vein, and because of the replacement of chalcopyrite by hematite, we may assume that the mineralizing fluids were sulfide deficient. Oxidizing conditions in a hydrothermal system could be caused by admixture of cool, oxygen-rich surface waters, and could lead to hematite formation. However, in the Champion vein hematite precipitated together with amorphous silica and therefore (see discussion on amorphous silica) it is most likely that no oxygenated surface waters were added to the hydrothermal system.

Conclusions

Vein sediments are a commonly observed feature in epithermal veins of the Bohemia mining district. In other epithermal deposits such sediments can be used to determine the original orientation of tectonically deformed vein systems.

Episodes of widespread vein sedimentation, such as during stages 3 and 4 in the Champion vein (Fig. 2), probably record an overall slowdown of fluid flow through the vein system, either in response to self-sealing (stage 3) or because of gradual cessation of hydrothermal activity (stage 4). In contrast, laminations in individual bodies (pockets) of vein sediment probably record small-scale local variations in fluid flow.

Pressure release due to hydraulic fracturing produced hydrothermal waters that were highly supersaturated in silica. When these waters cooled during ascent, large quantities of amorphous silica sediment were produced. The observed relationships between brecciation and vein sedimentation are in support of this interpretation. The deposition of hematite most likely indicates sulfide deficient hydrothermal fluids.

Large, sediment-filled cavities in marginal portions of epithermal systems probably have a higher preservation potential than sediment accumulations in the active central portions of such systems. Thus, there is a potential that these cavities contain a record that covers considerable portions of the life of the system. Such a long term record of temporal fluctuations of activity in hydrothermal systems may be somewhat analogous to the record of eruptive activity that is preserved in the stratigraphic sequence of volcanic centers.

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