

HYDROTHERMAL BRECCIA PIPE STRUCTURES – GENERAL FEATURES AND GENETIC CRITERIA – II. PHREATIC BRECCIAS

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ABSTRACT. Phreatic and phreatomagmatic breccias are the two end-member styles of hydromagmatic breccias. A previous contribution deals with phreatomagmatic breccias with an emphasis on their general features and those genetic criteria that allow an accurate and rapid recognition.

Phreatic breccias are presented here. Their general features, i.e. environment/depth of formation, general form/geometry, dimensions, contacts with the host rocks, fragments, matrix, alteration, mineralization, surface connection, fluidization and facies changes were examined. Furthermore, genetic criteria, very useful in phreatic breccia recognition are summarized.

Keywords: hydrovolcanism, phreatic breccias, descriptive breccia features, genetic criteria

INTRODUCTION

Hydromagmatic activity is responsible for breccia pipe genesis. The two-end member styles of hydromagmatic breccias are phreatomagmatic and phreatic ones. Their description and genetic aspects were widely presented during the last two decades (Sillitoe, 1985; Baker et al., 1986; Taylor & Pollard, 1993; Corbett & Leach, 1996; Mârza & Tămaș, 1997; Tămaș, 2002).

Phreatomagmatic breccias were recently presented by Tămaș & Milési (2002), who highlighted the genetic criteria that allow the early recognition of those types of breccia pipe structures. This paper deals with phreatic breccias, following the same structure as employed in our first contribution focused on hydromagmatic breccias (Tămaș & Milési, 2002).

GENERAL FEATURES OF PHREATIC BRECCIA PIPE STRUCTURES

Phreatic breccia structures, also called hydrothermal breccias by some authors, represent another type of hydromagmatic breccias (Lorenz, 1973; Nairn & Wiradiradja, 1980; Sheridan & Wohletz, 1981, 1983; Sillitoe, 1985; Baker et al., 1986; McPhie et al., 1993; Cas & Wright, 1995; Corbett & Leach, 1996 etc.). Their formation is the result of the indirect interaction between a magma body and an external source of water, namely between the magmatic heat and the external source of water. As compared to phreatomagmatic activity, which is caused by the direct interaction/contact between a magma body and water, the phreatic activity releases less energy, and consequently the dimensions of phreatic breccias are

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smaller. The indirect interaction between a magma body and a water supply induces specific characteristics to phreatic breccias as compared to the phreatomagmatic breccias. Almost all these peculiarities (we hope) will be presented below, in an attempt to point out phreatic breccias' peculiarities, as they are quite frequently misinterpreted as phreatomagmatic structures.

Environment / Depth of formation

There is a unanimous opinion (Sillitoe, 1985; Nelson & Giles, 1985; Hedenquist & Henley, 1985; Baker et al., 1986; Corbett & Leach, 1996 etc.) according to which phreatic breccia pipes formed at shallow levels in volcanic environments and geothermal fields. Phreatic breccia structures ubiquitously occur in the upper levels of hydrothermal systems, towards their discharge zone (Muffler et al., 1971; Nairn & Wiradiradja, 1980; Baker et al., 1986) where the physical conditions lead to hydraulic fracturing and hydrothermal/phreatic brecciation (Hedenquist & Henley, 1985). The common depth of formation is 200-300 m, seldom 500 m and only exceptionally 1,000 m (Sillitoe, 1985).

Hedenquist & Henley (1985) distinguished two types of phreatic eruptions. First one, called shallow phreatic eruption, forms at very small depth (meters, tens of meters) within an active geothermal system. In this case, a particular type of craters could be generated (collapse structures), which generally do not exceed 20m in depth. They formed due to dissolution of some mineral constituents of the country rocks during advanced argillic alteration, and consequently these types of craters and the underlying breccias do not have any equivalent extracraterial breccias. Such phreatic collapse breccia structures indicate that a boiling episode took place within the hydrothermal system beneath and thus their occurrence give additional evidences for the exploration activity.

The deep-seated hydrothermal/phreatic eruptions of Hedenquist & Henley (1985) took place at around 850-1,000 m depth. These deep phreatic events generate breccia conduits that represent the main access ways of the hydrothermal flux towards the surface. The major channeling of the mineralized solutions within the country rocks along these paths is mainly responsible for the genesis of high grade ore bodies.

As regards their occurrence, phreatic breccias were also reported as structures superimposed onto a predating phreatomagmatic breccia pipe, like at Wau, Papua New Guinea (Sillitoe et al., 1984), or at Roșia Montană, Romania (Tămaș, 2002). Furthermore, the structural control is frequently responsible for the location of phreatic breccia structures (Sillitoe, 1985; Berger & Morrison, 1990; Corbett & Leach, 1996).

General form / Geometry

Phreatic breccias usually occur as inverted cone structures with their narrow part towards the depth, sometimes as classical pipe-like bodies, or tabular bodies (breccia dykes). Commonly they have an irregular shape, which ranges from small veins, veinlets and breccia pockets organized in anastomosing

(stockwork-like) bodies, to massive bodies more or less tabular and/or columnar with frequent branching structures (Sillitoe, 1985; Baker et al., 1986).

Usually the branching occurs mainly on the hanging wall of the tabular breccia bodies (vein-like) and towards the upper part of the columnar or irregular bodies. Izawa & Cunningham (1989) described a quasi-columnar phreatic breccia body (Iwashita, Japan), which has a tooth-like bifid inferior termination (root-zone) and a funnel-like shape towards the surface (Fig. 1).

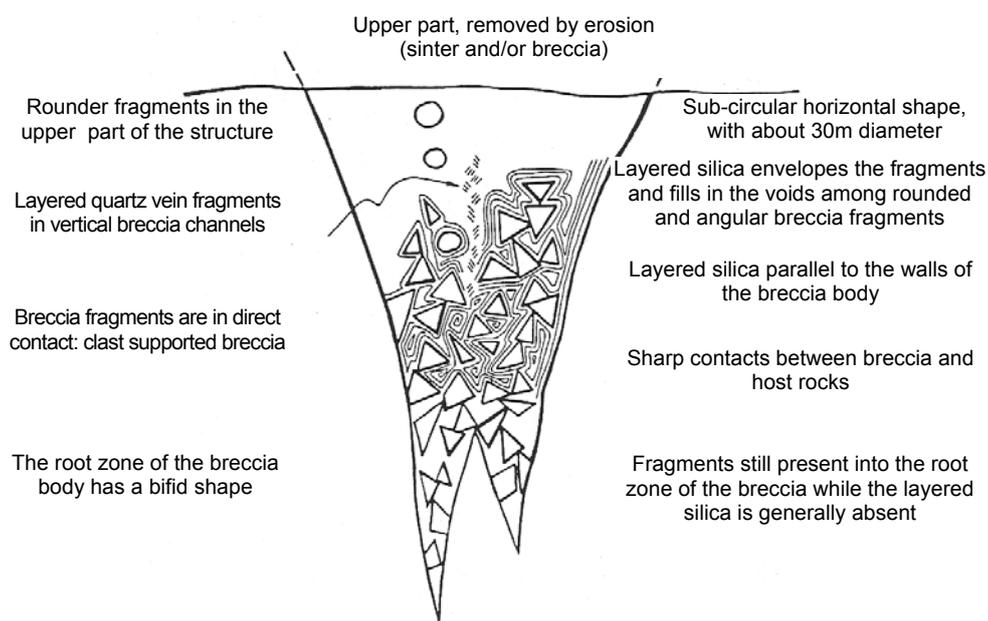


Fig. 1. Idealized geological cross-section of a phreatic breccia pipe from Iwashita – Iwato ore deposit (Japan). Tooth-like rooted zone of the breccia body and various breccia facies are to be noticed (in Izawa & Cunningham, 1989).

Dimensions

Phreatic breccias have variable dimensions, which range from small-sized columnar or tabular structures (centimeters – decimeters) to larger bodies up to several hundreds of meters, i.e. 350 m (Hedenquist & Henley, 1985), or 500 m (Sillitoe, 1985). Muffler et al. (1971) mentioned an unusual example, those of a hydrothermal crater from Yellowstone National Park (USA), with a diameter exceeding 1,200 m.

The vertical development of phreatic breccia pipes is smaller than that of phreatomagmatic breccias. Their height is intimately controlled by the hydrothermal solution boiling level, which commonly does not exceed 300 m in depth (Hedenquist & Henley, 1985), and also marks the rooted zone of the breccia bodies. The deep-seated phreatic breccias described by the same authors formed mainly by hydraulic fracturing may do not breach the paleo-surface (blind structure). When such

breccia structures finally reach the surface their height passes beyond 300 m, up to 850 – 1,000 m (Sillitoe, 1985).

Breccia – host rock contact features

The contacts of the phreatic breccia pipes with their host rocks are usually sharp, but they have an irregular shape, with multiples interpenetrations, which form finger-like contacts (Baker et al., 1986; Nelson & Giles, 1985). Sometimes there is a transition zone between the real breccia body and the host rocks, the latter often being intensely fractured and transformed into a stockworked area close to the breccia margins (Baker et al., 1986; Nelson & Giles, 1985; Izawa & Cunningham, 1989). The breccia walls are often sheeted fractured (Sillitoe, 1985; Nelson & Giles, 1985), giving rise, towards the edges of the breccia body, to different breccia facies with angular rock fragments, sometimes tabular (mosaic breccias, shingle breccias, crackle breccias, etc.). There are cases when phreatic breccia bodies are hosted by unfractured rocks, their limits being extremely sharp. In such cases hydraulic fracturing could be responsible for breccia genesis.

Fragments

The fragments of the phreatic breccias are more angular as compared to the fragments that occur within phreatomagmatic breccia structures, being dominantly angular and sub-angular. The clasts suggest minor distance of transport and mixing of the fragments, and consequently only an incipient processing/milling of the rock fragments in the breccia could sometimes be recognized. The fragments' dimensions range from centimeters-decimeters up to meters, but there are not very large fragments, which are quite common in the phreatomagmatic breccias (Tămaș & Milési, 2002).

A particular pattern is the absence of the juvenile fragments in phreatic breccias (Sillitoe et al., 1984; Baker et al., 1986). The main sources of the clasts inside the breccia body are the rocks that host the breccia structure. The rock fragments also represent remnants from previous hydrothermal depositional events as proved by specific hydrothermal textures, clay minerals or gangue minerals depositional sequences. The fragments, which were broken from the host rocks, commonly show an advanced degree of breaking (stockwork-like fissuration) and/or multiple brecciation/mineralization events.

The fragments are pervasively altered. The silica is widespread in phreatic breccias, as silicification of the matrix and the fragments, as well as massive or layered silica deposited in the open spaces of the breccia cementing thus the rock fragments.

The fragments participation exceeds the matrix participation in the case of phreatic breccias. The most common phreatic breccia facies is the clast supported one. The fragments are concentrated and make up a framework of clasts in direct contact with each other, preserving also many open spaces among them (Sillitoe, 1985) – open space breccias.

Matrix

The rock fragments are also accompanied by matrix and/or hydrothermal cement. The rock-flour type matrix has a variable participation, but it has obviously a minor participation (less than 50%, Sillitoe, 1985) as compared to the clasts. The matrix is composed by detritus of rock fragments (host rocks), clay minerals directly deposited from hydrothermal solutions, as well as comminuted ore and/or gangue minerals previously deposited.

The matrix is frequently replaced by silica or sulfides (Sillitoe, 1985), and it can often be repeatedly brecciated. In this case inside phreatic breccias matrix fragments from older brecciation stages could be found in a younger matrix or hydrothermal cement. It is worth mentioning that even if a rock flour type matrix could be generated during a phreatic evolution of a hydrothermal system, this type of matrix is not a defining indication of phreatic breccias as compared to phreatomagmatic breccias.

The cement is ubiquitously present in phreatic breccias. It is composed of ore and/or gangue minerals deposited within the open spaces or it may enclose the fragments, cementing them. The occurrence of large open spaces, filled with well crystallized minerals (quartz, sulfides, gold, silver, etc.), or compact masses of clay minerals is also specific for phreatic breccias. Due to multiple deposition events, spectacular cockade breccias or layered ore and gangue mineral sequences could be formed by phreatic brecciation. In this case the fluid inclusion analysis of the successive rims of hydrothermal minerals allow us to decipher the evolution history of the hydrothermal fluids responsible for brecciation and mineralization.

The amount of matrix participation and its various genetic types widened the breccia facies that might occur within a phreatic structure, i.e. matrix supported, clast supported, open space breccias, jigsaw breccias and so on.

Alteration

Phreatic breccias show specific hydrothermal alterations. The most important alteration is the silicification, which is usually very well developed (Muffler et al., 1971; Sillitoe, 1985). Beside the widespread silicification, other common alteration assemblages are: potassium silicate, phyllic, argillic (intermediate and advanced), and propylitic.

The alteration may be a pre-, sin-, or post-brecciation event. It may affect the clasts and also the matrix. For example, in the case of crosscutting veins, which are superposed onto a breccia structure, their own alteration halo and mineralization spread also into the breccia. In this last situation the breccia body is playing the role of a host rock for the subsequent veins.

Not only the breccia bodies are altered, but also the host rocks. For instance, the intense silicification of Cărnic II breccia from Cărnic hill, Roșia Montană (Tămaș, 2002) is also spread into the dacite host rock, which is intensely silicified, too.

Mineralization

Phreatic breccia pipes are closely genetically and spatially connected/related to hydrothermal systems, and consequently they represent in many cases high grade precious metals and/or base metals ore bodies (Sillitoe, 1985; Hedenquist

& Henley, 1985; Nelson & Giles, 1985; Baker et al., 1986; Corbett & Leach, 1996; Tămaș, 2002). Furthermore, due to the close genetic and spatial relationship between boiling and phreatic brecciation (Thompson et al., 1985; Hedenquist & Henley, 1985), their importance for metal deposition is more than evident.

Phreatic breccias are intensely mineralized. Precious and/or base metal deposition take place as impregnations in the matrix and/or rock fragments, as well as infillings of the open spaces, this latter case being the most important one, generating the so-called ore cement. As regards ore deposition – brecciation time relationship, several cases are to be mentioned:

- pre-brecciation mineralization: in this case ore fragments are to be found inside the breccia body;
- sin-brecciation mineralization: massive ore cement;
- post-brecciation mineralization: vugs infillings (ore-cement), ore rims around the breccia fragments, or even superimposed vein structures, which cut the breccia body.

As mentioned before, phreatic breccias may occur within an ancient phreatomagmatic apparatus. Breccia fragments that show specific phreatomagmatic peculiarities, as well as remnants from previous ore deposition events that pre-date the last phreatic brecciation stage are common (Sillitoe et al., 1984; Tămaș, 2002).

In many cases, phreatic breccias (breccia dykes and breccia pipes) have a downward transition into a classical vein structure (Baker et al., 1986).

Surface connection / extracraterial formation

Underground phreatic activity may generate surface breccia equivalent, concentrated close to the hydrothermal eruption vent. These surface breccia deposits are composed of angular rock fragments that accurately reflect the lithology of the area affected by phreatic brecciation (Muffler et al., 1971). Clast dimensions are generally small (centimeters – decimeters), but sometimes may rise up to 2-3 m (Nairn & Wiradiradja, 1980). Within extracraterial deposits, no juvenile clasts occur (Muffler et al., 1971; Nairn & Wiradiradja, 1980; Sillitoe et al., 1984; Baker et al., 1986). The rock fragments could be held together by a rough matrix composed of angular rock fragments, or by a clay minerals hydrothermal cement. The extracraterial deposits are weakly sorted and they have rarely stratification or grading (Hedenquist & Henley, 1985). There are no impact structures (bomb sag structures, for example). The surface development of those breccia deposits is limited from tens to hundreds of meters around the hydrothermal vent and only exceptionally up to 1-2 km. The width of the extracraterial deposits abruptly changes in direct relationship with the distance from the vent (Nairn & Wiradiradja, 1980).

Additional features

Being formed close to the paleosurface, phreatic breccia pipes are characterized by their smaller dimensions. The boiling of the hydrothermal fluids controls the genesis of phreatic breccias. They are underlined/marked by intense silicification zones and the abundance of clay minerals deposited within breccia bodies, as well as outside the breccia structure into extracraterial deposits. Phreatic breccias (intra- and extracraterial) contain very angular rock fragments, intensely altered.

Several facies changes are occurring within phreatic breccias horizontally as well as vertically. These changes as well as the main breccia types and their distribution zones are emphasized in the following sketches (Fig. 2, 3).

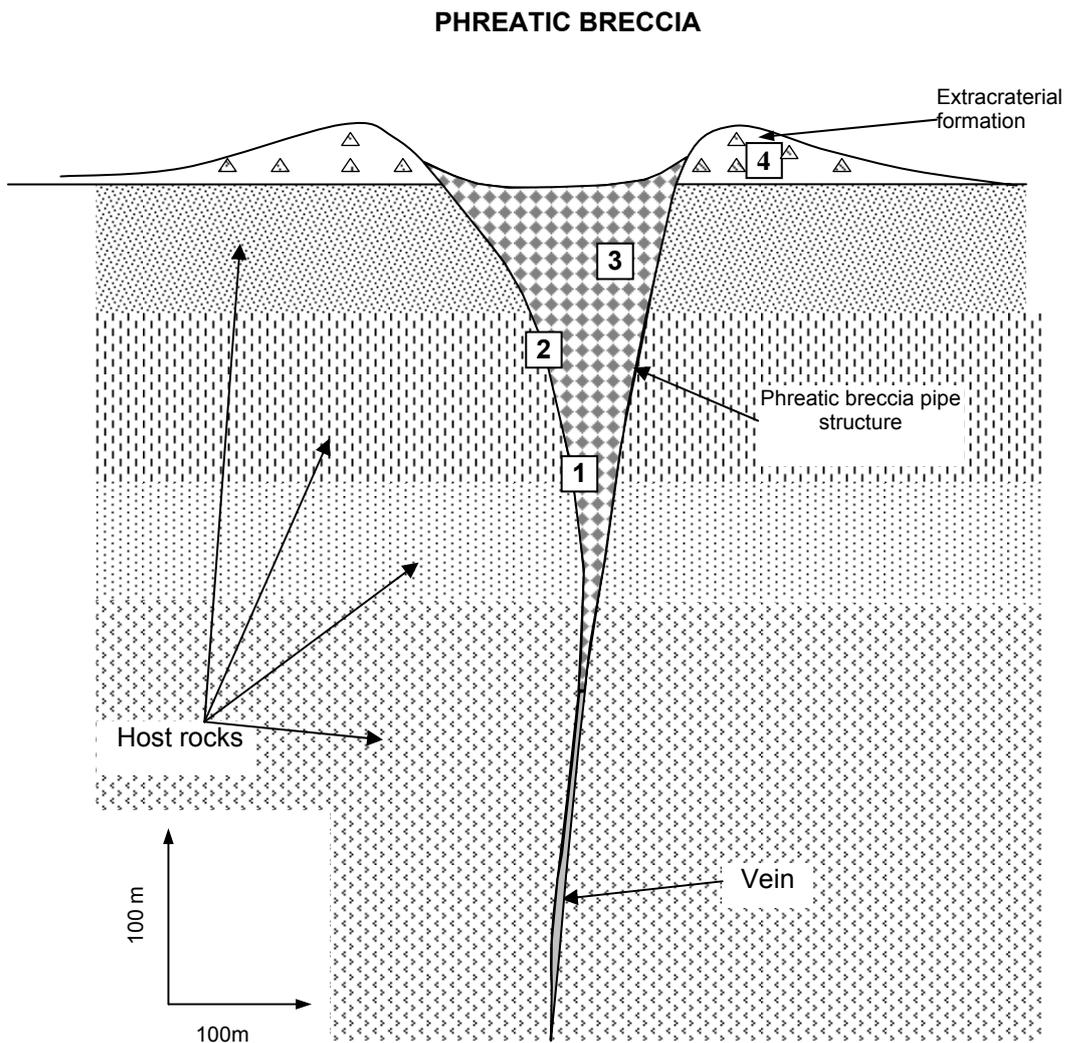


Fig. 2. Idealized cross section through a phreatic breccia pipe. The squares quoted from 1 to 4 represent different breccia facies within the pipe and the extracraterial formation. For details and legend see fig. 3 (after Tămaș, 2002, modif.).

GENETIC CRITERIA

The accurate recognition of the genetic type (phreatic breccia) is possible even almost at first sight in the field if we keep in mind several genetic criteria. These criteria are also accompanied by a wide spectrum of general features that sometimes are not specific enough to allow an accurate recognition. We give the list of general features of phreatic breccia pipes in Table 1.

Table 1

General features of phreatic breccia pipes.

Items	Description
Environment/ Depth of formation	Shallow depth of emplacement; volcanic/geothermal
General form/ Geometry	Inverted cone, pipe like but commonly irregular bodies (which range from small veins and veinlets to large pipes, tabular masses, and anastomosing bodies) ³
Dimensions	Horizontal dimensions: several meters to hundreds of meters; usually up to 500m; Vertical dimensions: less than 300m (boiling level).
Breccia – host rock contact features	Sharp complex finger-like contacts ; gradation to stockwork fracturing. Marginal sheeted zone and rocks adjacent to the pipe may be densely crackled, and lead to jigsaw (mosaic) or crackle breccias.
Fragments	Fragments mixed. Shape: - angular to sub-rounded, generally more angular ; The movement of the fragments within the pipe is often minor . Composition: - no juvenile fragments ; - fragments from earlier mineralization events (with typical features of epithermal mineralization, such as crustiform banding, hydrothermal mud, gangue minerals); - significant proportion of stockworked country rock fragments and earlier breccias .
Matrix	- Variable amount of matrix, often low in volume , usually replaced; - matrix less than 50%, fragment dominated ; - rock flour, hydrothermal clays and gangue minerals; - frequent open spaces and fragment supported breccias ; - usually fragments are covered by hydrothermal cement (ore or gangue minerals); - rock flour matrix usually absent in the upper parts of the pipe .
Alteration	- Pervasive alterations (silicification, potassium silicate, phyllic, argillic); - clasts onion-skin or exfoliated textures; - hydrothermally altered clasts in a clayly matrix; - widespread occurrence of quartz as both pervasive replacement of, and cement to fragments.
Mineralization	- High grade mineralization mostly as vugs infilling, replacement of matrix and clasts; - ore clasts from earlier mineralization events ; - ore cement ; - overprinting veins;

³ Frequently phreatic breccias are located within an ancient phreatomagmatic apparatus or may occur as overprinting structures.

Items	Description
	- often breccias continue downward into vein-type mineralization.
Surface connection	- No juvenile lithic pyroclasts; - typically poorly sorted; - angular blocks, commonly hydrothermally altered supported in a silty – hydrothermal clay matrix; - bedding generally absent to poorly developed; when present includes wedging, pinch and swell structures, dune form, and more common sub-parallel bedding; - limited area of development, usually hundreds of meters around the vent (300-500m), but less than 1km.
Fluidization	minor
Facies changes	Relation with an impermeable caprock horizon – shale bed or a zone of silicification formed at the base of boiling water table. The presence of hydrothermally altered clasts and hydrothermal clay minerals in the matrix of the fall-out apron in contrast with the breccias found in tuff rings surrounding maar volcanoes, which are generally unaltered.

CONCLUSIONS

A broad range of general descriptive features with more or less important genetic significance is listed in Table 1. Their importance as regards the recognition of the genetic style of brecciation differs from case to case. Usually, the occurrence and furthermore the recognition of several features from those summarized above allow an appropriate genetic interpretation.

It is obvious that the genesis of a phreatic breccia pipe body is not the mere result of a single brecciation mechanism. Along with phreatic brecciation, other brecciation mechanisms like fluidization, hydraulic fracturing, tectonic brecciation, collapse, chemical brecciation may also significantly contribute to the genesis of a breccia as a whole structure.

It is not our ultimate scope to describe in detail all breccia characteristics in order to decipher its genesis. In our opinion, it is more important to recognize those features that are very characteristic for a genetic type of breccia. A list of key genetic criteria, which usually are generated during phreatic brecciation is summarized in Table 2.

Table 2

Genetic criteria for phreatic breccia pipes.

Items	Description
Environment/Depth of formation	Shallow level of emplacement (300-500m) in close relationship with a subjacent hydrothermal system; they could occur as overprinting structures superposed to older phreatomagmatic breccia pipes.
General form/Geometry	Pipe-like or inverted cone breccia bodies; frequent irregular bodies – veins, veinlets, pockets – that may form anastomosing breccia bodies, as well as tabular structures – breccia dykes.
Dimensions	Variable horizontal dimensions: millimeters – centimeters – meters (veinlets, veins); meters – tens of meters – hundreds of meters (breccia pipes and breccia dykes). Variable vertical dimensions: meters – tens of meters – hundreds of meters

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Items	Description
	(350-500m).
Breccia – host rock contact features	Sharp limits often with irregular shape and frequent interpenetrations; stockwork marginal transition zone towards unbrecciated host rocks are frequent.
Fragment characteristics	Mainly angular, sub-angular; transport and milling of the clasts are minor. No juvenile clasts; Fragments frequently indicate reiterated brecciation and mineralization events. The clasts are hydrothermally altered, sometimes being cemented by clay minerals.
Matrix	Matrix and cement (<50%); open spaces; Important participation of clay minerals and quartz; Ore and/or gangue minerals cement.
Alteration	Pervasive; mainly silicification and clay minerals.
Mineralization	High grade ore bodies, but with smaller dimensions as compared to phreatomagmatic breccias. Ore cement, vugs infilling, subordinately impregnations; Replacement of the matrix and/or the clasts.
Surface connection	Unsorted, unstratified extracraterial deposits with limited area of development; the rock fragments are usually angular; abundant clay minerals.
Fluidization	Minor
Facies changes	Close spatial and temporal relationship with boiling; cockade breccias.

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