CHARACTERISTICS AND DEVELOPMENT OF CARBONA-STYLE REPLACEMENT TIN MINERALIZATION IN WEST CORNWALL

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Granite-hosted cassiterite-bearing replacement bodies or "carbonas" represent a restricted style of tin mineralization found in the Cornubian orefield. This paper reviews historical sources and presents new data on carbonas which occur in the Lands End and Carnmenellis Granites. On a county-wide scale their historical tin production is low, but individually they may contain in excess of 100,000 tonnes of ore with a grade of up to 1.6 % Sn. In addition, some of the bodies contain small-scale, economic copper ores. The carbonas are irregularly-shaped bodies of mineralized/ altered granite which sometimes show a gross tabular or pipe-like geometry. The pipe-like bodies have a maximum diameter of 30 m with a long axis up to 200 m in length, and they show vertical, horizontal or inclined attitudes. The tabular bodies may have strike lengths up to 150 m, widths up to 15 m and down-dip extent up to 100 m, in general however their dimensions are smaller. Carbonas are characterised by the pervasive hydrothermal alteration of the granite to chloritic, sericitic and tourmalinitic assemblages which may be strongly overprinted. Mineralization consists of disseminated cassiterite with arsenopyrite, specular hematite, pyrite, quartz and fluorite, and rarely chalcopyrite, bornite and chalcocite. Published fluid inclusion data for these deposits are absent, but results of current studies show dominance of two phase liquid-vapour inclusions characterised by a homogenisation temperature range of between 125 and 393°C and a salinity range of 5.5 to 22.1 equiv. wt. % NaCl. These fluids are believed to be dominantly magmato-hydrothermal in origin, with some evidence for late-stage meteoric fluid involvement during reactivation. Studies of quartz-hosted, healed microfracture planes within the mineralized alteration zone reveal strong microfracture control on fluid flow pathways, alteration intensity and ore localization. It is suggested that the mode of carbona development defines their detailed geometry. The formation of localized microfracture zones about a narrow vein/fracture resulted in dominantly tabular-shaped bodies. Pipe-like bodies are more problematic, but were probably related to the intersection of two or more different fracture sets along an irregularly shaped fracture zone.

INTRODUCTION

Granite-hosted (endogranitic) tin mineralization in southwest England is characterised by fracture systems which show marked variations in their time of formation, alteration, distribution, structure and geometry. The classifications of Hosking (1964; 1969; 1988) and Taylor (1979) recognise five styles of endogranitic tin mineralization: 1) lodes; 2) stockwork systems; 3) floors; 4) replacements and carbonas and 5) disseminations within dykes. Within the orefield, three principal mineralizing stages are recognised (Bromley and Holl, 1986; Jackson et al., 1989): a pre-batholith stage of sediment-hosted mineralization (Fe-Mn-Cu); a syn-batholith (or main-stage) characterised by Sn-W-bearing stockwork mineralization followed by (Sn)-(Sn-Cu) bearing lode-style mineralization with which the carbona-style deposits are believed to be associated, and a post-batholith stage of epithermal (or crosscourse) vein mineralization (Zn-Pb-Ag etc.) and pervasive granite kaolinization. Most tin production has been derived from complex lode zone systems (Farmer and Halls, 1993; Dominy and Camm, 1996), but a number of mines have been reliant on carbona deposits. Irrespective of style, mineralization is often located near porphyry dykes, along the axis of the granite batholith, or commonly at the batholith margins/roof zones (Jackson et al., 1989). Pervasive wallrock alteration zones are a common feature of the lodes and often contain economic amounts of tin mineralization distributed over substantial widths (Farmer and Halls, 1993; Dominy et al., 1996). Wallrock alteration is an important characteristic of carbona systems, which represent regions of wholesale wallrock alteration/replacement by metasomatic processes. This paper reviews a number of carbona systems which have received little attention in recent years' because of lack of exposure and exploration activity within the orefield. Most of the information has been acquired through literature searches and study of abandoned mine plans. All aspects of deposits are reported including mineralogy, structure, grade and tonnage. Where tonnage and grade data are presented, either historical sources or calculations by the authors based on inferred volumes and a bulk tonnage factor (density) of 2.65 tonnes/m³ were used. New fluid inclusion data are presented for three carbona deposits, one of which is described here for the first time. Similarly, lithogeochemical data of carbona samples are also provided for the first time for one deposit.

DEFINITION AND CHARACTERISTICS OF CARBONAS

Although carbona orebodies are not widespread in southwest England and contributed negligibly to the total tin output of the region, a small number of mines were developed because of the presence of a carbona and made substantial profit. Henwood (1843) suggests that the word carbona originates from the Cornish language, but Hunt (1884) reports that it is an Aramaic term meaning "a place rich in good things - a treasury". Moissenet (1877) and Collins (1912) describe carbonas as "irregular tin deposits occurring in granite". Phillips and Louis (1896) provide a similar definition, but erroneously include closely-spaced vein systems which are usually termed stockworks (Collins, 1912; Dominy et al., 1995a). Hill and MacAlister (1906) describe carbonas as "irregular, more or less horizontal pipes, passing into the [granite] country rock along cracks..." with reference to the St. Ives Consolidated Mine Great Carbona body. Spargo (1865) records ".extraordinary excrescences of ore in the sides [of lodes]" called carbonas within the St. Ives Consolidated Mine. The feature of alteration halos about lodes is recognised by Foster (1855) who stated that "many of the...most productive tin lodes in Cornwall are simply tabular masses of altered granite adjacent to fissures", but he does not use the term carbona. Jackson (1975) describes a metasediment-hosted deposit related to
granite tongues within the Levant Mine as a carbona, this does not conform to the common granite-hosted definition. In the Camborne-Redruth district the term has been used imprecisely to describe irregular alteration halos about veins (Hill and MacAlister, 1906).

There is thus some confusion in the literature to the precise definition of carbonas, however it is clear that the key points in any definition must be "irregular", "tin-bearing" and "altered granite". The authors suggest a definition of "irregularly shaped bodies of highly altered tin-bearing granite" which is similar to that proposed by Hosking (1964; 1988) and the majority of earlier workers (op. cit.).

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**ST. IVES DISTRICT CARBONAS**

The St.Ives district, stretching from Zennor in the south to Hayle Estuary in the north, was one of the most notable mining areas in Cornwall. Mines formerly worked included; St.Ives Consolidated Mines, Providence Mines, Wheal Trenwith, Wheal Reath and Giew Mine (Dines, 1956; Noall, 1982; 1993).

**St. Ives Consolidated Mines**

The Great Carbona of St. Ives Consolidated Mines [SW 506 3971 is probably the most noted in the orefield (Henwood, 1848, 1865; Phillips and Louis, 1896; MacAlister, 1907; Collins, 1912; Dines, 1956; Noall, 1993) and was described by Hill and MacAlister (1906) as pipe-like. It was discovered in the 1830s whilst working the Standard Lode (lode-style deposit) between the 35 and 77 fathoms levels, when the workings intersected three sub-horizontal (tabular?) carbonas named No. 1, Lawrys and Great (Figure 2). These bodies were followed and found to widen and finally merge to form The Great Carbona below the 77 fathom horizon (Figure 2).

**Figure 1:** Map showing the location of the Lands End and Wendron "carbona" areas.

**Figure 2:** Cross-section of the St. Ives Consols Great Carbona system. No. 1 (\#1) and Lawrys (\#2) carbonas were intersected and followed on the 35 and 57 fathom levels respectively. The Great Carbona was defined from the 77 fathom level (\#3) and southwards where it enlarged greatly. The arched shape of the body is believed by Hosking (1969,1988) to mirror the contact between two granite stages. Daniells Lode carbona lies directly beneath the Great. Redrawn and edited from Hosking (1988).
The Great Carbona system plunges at up to 40° towards the south. It displays a diameter range from about 1 to 20 m with an average of 10 m and a down-dip extent of some 235 m. Minerallogically it is characterised by alkali feldspar, quartz, chlorite, tourmaline and cassiterite with minor fluorite, chalcopyrite, bornite and pyrite. The wallrocks show a gradual transition from relatively unaltered granite to mineralized granite (Phillips and Louis, 1896) and where strong mineralization was absent the body could be followed as a narrow vein with a weak alteration selvage. No tonnage for the system is quoted in the literature or mine records but, based on the quoted dimensions, must have been in excess of 80,000 tonnes. Collins (1912) quotes an average grade of about 1% Sn for the Great Carbona.

Below the Great Carbona lay the sub-vertical tabular Daniels Lode carbona (Figure 2). The structure was up to 12 m wide, traceable along strike for 145 m and down-dip for 110 m. It was larger than the Great, and probably contained in excess of 175,000 tonnes of ore at a grade suggested by Collins (1912) to be higher than the Great’s average of 1% Sn. Mineralogically Daniels Lode carbona showed the same characteristics as the Great Carbona, but does not appear to be structurally linked to it.

Providence Mines

A number of carbona bodies were reported within the Providence sett [SW 523 384] which were generally related to lodes (Henwood, 1865; Collins, 1912; Dines, 1956). The old mine plans show seven bodies, five related to the north wall of the Standard Lode, and two south of it. The bodies varied considerably in size, as shown by their estimated tonnages: No. 1- 31,500 tonnes; No. 4- 200,000 tonnes; No. 5- 11,000 tonnes; No. 6-18,000 tonnes and Unnamed- >5,000 tonnes. The Nos. 2 and 3 carbonas were located to the south of Standard Lode and appear to be smaller than the others. Collins (1912) described the No. 3 carbona which was related to the intersection of the Wheal Comfort and Wheal Laity Lodes 190 m below surface. He reported that, close to the contact with Comfort Lode, the carbona contained a rich mass of quartz, feldspar and tourmaline with cassiterite in an area 5 m wide and 10 m long. Some 10 m below this point the carbona reduced to a narrow vein which continued to some depth. No information was available as to the grade of any of the carbonas within the sett.

WENDRON DISTRICT CARBONAS

From the 17th century onwards the Parish of Wendron saw surface and underground mining commence alongside already well established tin streaming activities (Hamilton-Jenkins, 1978; Brooke, 1994). The majority of mines depended upon lodes for tin production, but in a few cases production came exclusively from carbonas. Collins (1912) quotes an average grade of about 1% Sn for the Great Carbona. Cunnack (Brooke, 1993) reports that the ore was of great richness, but below the 90 fathom level the cassiterite disappeared and the body became dominated by gibertite mica. Dines (1956) reports that in cassiterite-rich regions the granite was strongly kaolinized, though very locally. The distribution of tin within the carbona was not uniform, but the ore-zone was followed down-dip from the 40 to the 100 fathom level (108 m). The carbona also contained small amounts of copper ore of which there is no recorded production.

South Wendron Mine

The deposit at South Wendron [SW 705 301] was a pipe-like body with an oval section measuring 3 m by 6 to 18 m in plan (Hill and MacAlister, 1906; Dines, 1956). The body contained cassiterite, quartz, chlorite, gibertite, fluorite and tourmaline with pyrite and chalcopyrite (Foster, 1878). Production from the mine was small, with only 9.6 tons of tin concentrate produced between 1875 and 1880 (Burt et al., 1987).

Balmynheer Mine

This tabular body [SW 344 704] was described by Hill and MacAlister (1906) and Dines (1956) and was characterised by a 0.15 m wide quartz and clay vein which had a strike 058° and dip of 60° towards the north. The carbona was located on the footwall of the vein and varied in thickness between 9 and 15 m. It had a strike extent of about 65 m and a general dip in the same angle and direction as the vein. Cunnack (Brooke, 1993) reports that the mine was worked to a depth of about 100 m, but tin values became poor at depth. Mineralogically the carbona contained cassiterite, quartz, gibertite, chlorite, pyrite and spalerite with minor wolframite. In 1876 some 2,200 tons of ore (approx. 0.9% Sn) were extracted (Burt et al., 1987).
Halabezack Farm

This little known deposit near Porkellis, was reported by Fox (1868) who describes an open pit and adit worked for tin. The carbona was associated with a 0.6 m wide quartz/clay vein which displayed an east-west strike and dip 62° north. Cunnack (Brooke, 1993) states that the mineralization was hosted within a quartz-phyric granite variant known locally as "elvan". The zone of alteration and mineralization was 20 fathoms wide (36 m) and worked to a depth of about 80 fathoms (144 m). Mineralogy was dominated by cassiterite with specular hematite and pyrite, and presumably chlorite etc. Tin grades varied from 0.3 to 1.7 % (Fox, 1868) though Cunnack (Brooke, 1993) suggests an average grade of 0.7 % Sn, no tonnage information is available.

Wheal Roots

This little known mine [SW 682 315] was first reported by Hamilton-Jenkin (1978) who considered it to be part of Wendron Consols Mine, following its discovery during the driving of an adit for the purpose of tourism. By 1987, the majority of the original Wheal Roots workings were cleared, and the northermost stope or "carbona chamber" was accessible. The carbona was tabular in form, centred on the quartz vein, and about 4 m wide at its widest. Tin is enriched (x 340) in the carbona samples compared to an average of 14 ppm generally reported from unaltered Carnmenellis granite (Alderton, 1993).

WHOLEROCK GEOCHEMICAL STUDIES

Major element analyses of six samples from the core of the Wheal Roots carbona are shown and compared with analyses of fresh granite in Table 1. Carbona and granite analyses were performed using ICP-AES on samples prepared by a standard lithium metaborate fusion technique. Selected oxides in both the carbona and granite samples were ratioed to silica to show relative enrichment and depletion in concentration (Table 1). Most notably Mg and Fe are enriched in the carbona, which is consistent with extensive chlorite development. Fe enrichment is also explained by the presence of specular hematite. Ca is also enriched in the carbona and can explained by the development of fluorite within the alteration assemblage, while depletion of Na and K is controlled by the dissolution of feldspars during alteration, although the presence of white mica within the altered rock tends to buffer the K concentration. Tin is enriched (x 340) in the carbona samples compared to an average of 1 ppm generally reported from unaltered Carmmenellis granite (Alderton, 1993).

FLUID INCLUSION STUDIES

Fluid inclusion studies have been undertaken for the first time on carbona samples to elucidate the nature of the mineralizing fluids. Microthermometric analyses were carried out using a Linkam heating-freezing stage, on doubly polished 100 pm thick sections. Calibration was undertaken using the high para purity compounds and synthetic fluid inclusions and the homogenization temperature quoted represents the disappearance of the vapour bubble. No pressure corrections have been applied to the homogenization temperature data, which must be regarded as the minimum trapping temperature. Salinity values were determined from the last ice melt temperature using Flincor computer software (Brown, 1989). Fluid salinity is expressed as equivalent weight percent sodium chloride (equiv. wt. % NaCl). Fluid composition was determined by comparison of first ice melting temperature (eutectic temperature) with those quoted in Shephard et al. (1985). The recognition of primary inclusions was difficult because of the lack of crystal faces so in most cases secondary and pseudo-secondary inclusions were investigated.

St. Ives Consolidated Mines, Great Carbona

Microthermometric measurements were undertaken on quartz-hosted inclusions from a sample formerly in the collection of the late Professor K. F. G. Hosking. The sample was dominated by cassiterite intergrown with tourmaline, chlorite and quartz and was reported to

<table>
<thead>
<tr>
<th>Element</th>
<th>Carbon</th>
<th>Roots Granite</th>
<th>Other Granite</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>70.55</td>
<td>71.93</td>
<td>72.02</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>12.35</td>
<td>15.64</td>
<td>14.98</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.2</td>
<td>0.22</td>
<td>0.23</td>
</tr>
<tr>
<td>MgO</td>
<td>0.85</td>
<td>0.41</td>
<td>0.35</td>
</tr>
<tr>
<td>MnO</td>
<td>0.09</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>ΣFeO</td>
<td>6.42</td>
<td>1.65</td>
<td>1.51</td>
</tr>
<tr>
<td>CaO</td>
<td>2.16</td>
<td>0.7</td>
<td>0.64</td>
</tr>
<tr>
<td>Na₂O</td>
<td>1.19</td>
<td>2.93</td>
<td>3.05</td>
</tr>
<tr>
<td>K₂O</td>
<td>4.1</td>
<td>5.39</td>
<td>5.27</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.19</td>
<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
<td>Total</td>
<td>98.1</td>
<td>99.15</td>
<td>98.34</td>
</tr>
<tr>
<td>Sn</td>
<td>0.48</td>
<td>0.48</td>
<td>0.48</td>
</tr>
<tr>
<td>Element ratioed to SiO₂ x 1000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Fresh granite from No. 1 level Wheal Roots.
- Fresh granite from Hemiss Quarry.
- bdl below detection limit for XRF.

TABLE 1. Average major element values (wt. %) by ICP-AES for altered carbona granite and fresh granite from Wheal Roots and elsewhere in the Wendron area. Tin analysis by XRF.
have been collected from the 77 fathom level of the Great Carbona. The inclusion population was dominated by the liquid-vapour type, with a smaller number of liquid- and vapour-only inclusions. Homogenization temperature and salinity values ranged from 256 to 398°C and 10.4 to 23.3 equiv. wt. % NaCl respectively (Figure 4). The inclusions showed a dominant eutectic temperature close to -20.8°C, implying a NaCl-H$_2$O fluid composition, though a few yielded temperatures near -22.9°C suggesting a NaCl-KCl-H$_2$O composition.

**East Wheal Lovell, North Lode Carbona**

Microthermometric measurements were undertaken on quartz-hosted inclusions from a sample reported to be from the 50 fathom level. The sample of strongly chloritized granite was dominated by dense chlorite aggregates intergrown with tourmaline and minor cassiterite and quartz. The inclusion population was composed dominantly of the liquid-vapour type, though a small number of liquid- and vapour-only types were observed. Homogenization temperature-salinity measurements showed ranges of 253-367°C and 12.3-21.6 equiv. wt. % NaCl respectively (Figure 4). Only four eutectic temperatures were determined which suggested a NaCl-KCl-H$_2$O composition.

**Wheal Roots Carbona**

Measurements were undertaken on inclusions hosted in quartz from the pervasively altered centre of the carbona. The inclusion population was dominated by the liquid-vapour type, though a lesser number of liquid-only inclusions were also observed. Homogenization temperature and salinity values ranged from 125 to 398°C and 5.5 to 22.1 equiv. wt. % NaCl respectively. The data fall into two groupings; i) 125 to 236°C (5.5 to 10.2 equiv. wt. % NaCl) and ii) 233 to 398°C (15 to 22.1 equiv. wt. % NaCl: Figure 4). The group i) inclusions indicated a NaCl-H$_2$O fluid composition whereas group ii) inclusions showed both NaCl-H$_2$O and NaCl-KCl-H$_2$O compositions.

Microthermometric studies of carbona-hosted fluid inclusions reveal an overall homogenization temperature range of 125 to 398°C and a salinity range of 5.5 to 22.1 equiv. wt. % NaCl (Figure 4). Comparison with other studies from the orefield suggests that data in the range 233 to 398°C are magmato-hydrothermal fluids in origin. This conclusion is in-line with Alderton (1993) who suggests a homogenization temperature and salinity range of 300-500°C and 10-25 equiv. wt. % NaCl respectively for main-stage Sn-Cu mineralizing fluids. The lower temperature-salinity group (i) data for the Wheal Roots carbona are typical of dominantly meteoric fluids within the range <200-350°C and <10 equiv. wt. % NaCl (Alderton, 1993) associated with late-stage fracture reactivation.

**MICROFRACTURE STUDIES**

Carbonas are characterised by large volumes of pervasively altered granite which is often associated with a variable narrow macro-fracture. Studies were undertaken to evaluate the role of microfracturing in carbona development. The granitic rocks of south-west England contain numerous microfractures which are microscopically observed in quartz as multiple planes of healed tensile or shear fractures, which can be differentiated by observation of their morphology, orientation and shape of contained inclusions (Krantz, 1983; Lespinasse and Cathelineau, 1990; Westerman, 1995). Microfracture displacement can be observed along some grain boundaries and at the intersections of two or more microfractures.

The real-space three-dimensional orientation of the microfractures can be determined using field oriented samples (Prior et al., 1987) followed by studies using a Universal Microscope Stage (U-stage) technique (Westerman, 1995; Passchier and Trouw, 1996). In this study, two orientated, doubly polished, thin sections 100 μm thick were prepared for a sample collected from Wheal Roots. These were cut along mutually perpendicular planes so that microfractures in all possible orientations could be studied. A number of standard thin sections were also prepared so that microfracture densities could be determined.

U-stage measurements on the sample revealed that the inclusion planes showed a preferred strike orientation about the long axis of the carbona (055-060°) ranging from 035° to 075° (Figure 5). Dip values of the planes were generally >75° with a dominant direction northwards, although a few south-dipping ones were seen. These observations corroborate with previous findings, which show that microstructures generally mirror macrostructures within the granites of south-west England (Dominy et al., 1995b; Westerman, 1995; Dominy et al., 1996). Preliminary

**Figure 5:** Rose diagram showing the dominant strike orientations of microfracture planes hosted in quartz within the Wheal Roots carbona. All planes show dip values in excess of 75°.

**TABLE 2:** Table of microfracture density data from a 0.8 m traverse from the central quartz vein within the Wheal Roots carbona. Samples 01 to 06 within carbona, 07 outside.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Granite Type</th>
<th>Position</th>
<th>MF Density</th>
<th>Fl Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>WR/01</td>
<td>Chloritized</td>
<td>0.05</td>
<td>16</td>
<td>1347</td>
</tr>
<tr>
<td>WR/02</td>
<td>Chloritized</td>
<td>0.2</td>
<td>13</td>
<td>1198</td>
</tr>
<tr>
<td>WR/05</td>
<td>Chloritized</td>
<td>0.35</td>
<td>11</td>
<td>1011</td>
</tr>
<tr>
<td>WR/06</td>
<td>Chloritized</td>
<td>0.45</td>
<td>8</td>
<td>679</td>
</tr>
<tr>
<td>WR/07</td>
<td>Sericitized</td>
<td>0.8</td>
<td>5</td>
<td>495</td>
</tr>
</tbody>
</table>

1Position in m from the central quartz vein within the carbona.
2Density of microfractures in number per mm.
3Density of fluid inclusions per mm².

Microthermometric studies of plane-hosted inclusions reveal the same homogenization temperature-salinity groupings and characteristics as previously reported in this paper. Table 2 shows microfracture and fluid inclusion data that demonstrate a high density within the carbona body. Weakly sericitized granite on the carbona margin shows some development of microfracturing, but less than that of the orebody. The higher values are in agreement with previous studies in south-west England and elsewhere which demonstrate a "steam aureole" effect around fossil fluid channelways in granites (Yermakov, 1967; Dominy, 1993; Dominy et al., 1996a).
DISCUSSION

Carbonas are an unusual style of tin mineralization observed in the south-west England orefield. Their genesis is likely to relate to the main-stage tourmaline-cassiterite mineralization which occurred between 287 and 284 Ma (Chesley et al., 1993; Chen et al., 1993). They are dominated by zones of pervasive wallrock alteration in which cassiterite has been deposited erratically, but in enough quantity to have been of economic importance. Over the entire orefield the historical output of tin from carbonas has been minimal, but locally it was of importance. Consequently, carbonas represent relatively small tonnage bodies with highly variable grades. Carbona-style mineralization appears a peculiarity of Cornwall however, Hosking (1988) reports that the Sungai Besi Mine in Malaysia contained a number of carbonas developed in granite just below a marble cover. This style of mineralization probably does exist in other granite-hosted tin provinces, but have not been recognized as such.

Fluid inclusion data presented in this paper show the carbona-fluids plot in the same field as those of a magmato-hydrothermal origin (Figure 4), thus revealing a genetic link with the main-stage mineralizing fluids described by Alderton (1993). Later reactivation of the narrow vein(s) which pass through some of the bodies was probably related to lower temperature-salinity meteoric fluids, as seen in the Wheal Roots carbona.

The formation of most types of hydrothermal mineral deposits requires the focusing of substantial volumes of fluid along discrete, well-defined channelways often on a large scale. Within a single deposit the concentration of ore is like-wise reflected by small-scale channelling of fluid flow along fractures. Microscopic studies of samples from the Wheal Roots carbona reveal a general microfracture trend within ±020° of the direction of the body and a higher density of microfractures and fluid inclusions about the body (Figure 5; Table 1). This is a characteristic of other vein-related systems throughout the orefield, in which microfractures exerted a strong control on fluid flow and the distribution and intensity of alteration (Westerman, 1995; Dominy, 1993, 1994; Dominy et al., 1996). The narrow "in-carbona" veins and associated microfracture systems suggest that carbona development was dominantly fracture-controlled. Variations in fracture development about a planar or linear conduit are believed to give rise the overall tabular or pipe-like carbona geometries. Tabular bodies display the simplest model for development involving the initial formation of a precursory macrofracture and possibly some microfractures. This shows local spatial variations and, when re-activated, results in the formation of a more localized microfracture zone with some void space possible. Fluid flow through this high permeability and connectivity zone results in wallrock alteration and mineralization (Figure 6). The development of the pipe-like system is more complex and may involve the intersection of two or more differently oriented fracture sets (Figure 7). It has long been recognized that movement along an irregular fracture plane results in the development of dilatent zones of high fluid permeability, and thus as act as loci for mineral deposition and water/rock interaction (Newhouse, 1940). An initial fracture forms which is intersected by a further plane(s) at an angle to it, resulting in a linear zone of high permeability and connectivity. The strike and dip of the intersecting fractures defines the connection zone which will be in the gross form of a pipe. The focused flow of fluid along this zone will result in wallrock alteration and mineralization. In either case, carbona development is related to a complex multi-stage history of fracturing, fluid flow, and mineral deposition. The more irregular carbonas probably reflect a more complex pattern of feeder fracture, microfracture and fluid flow.

Pervasive granite alteration, a characteristic of carbonas, is significantly wider than the associated macro-fracture(s). The alteration can be considered in terms of hydraulic disequilibrium between the fracture fluids and the pore fluids within the wallrock, as well as the chemical disequilibrium between the mineralizing fluid and the wallrock minerals. Since these fluids were dominantly formed at magmato-hydrothermal temperatures and confined at lithostatic pressures, they were able to produce gross metasomatic changes in the wallrocks, leading to mineralogical and textural reconstitution (Halls, 1987). Theoretical modelling suggests that diffusion can account for alteration zones up to about 5 m in width, but larger zones must involve the bodily flow of fluid through the rock (Zharikov and Zaraisky, 1991). Within the carbonas fluid flow was predominantly via microfractures which enhanced access to grain boundaries and permeability. Localized variations in, and interplay between vein and

![Figure 6: Stages in the development of a tabular carbona.](image)

![Figure 7: Stages in the development of a pipe-like carbona.](image)
Cassiterite-bearing carbonas

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