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Mineralization at Le Pulec, Jersey, Channel Islands

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SUMMARY. Veins cutting the Brioverian sediments at Le Pulec, Jersey, were worked in the 1870s for silver and lead. Investigation of the mineralogy of both the sediments and cross-cutting veins has shown a complex mineralization history. Siltstones close to the contact with the North-West granite have been bleached, silicified, and dolomitized, and this has been accompanied by the introduction of pyrite, marcasite, and arsenopyrite. Later vein mineralization contains sphalerite and ferroan dolomite accompanied by lesser amounts of galena and chalcopyrite and minor quantities of argentian tetrahedrite, native antimony, bournonite, cubanite, plagionite, and stibnite. The mineral assemblage is unlike the other mineral occurrences of Jersey that have previously been described.

LE PULEC (UTM 547549) is a small bay on the NW coast of Jersey, close to the granite quarries of L'Etacq. A contact between the North-West granite which is of Cadomian Age, 490 ± 15 Ma (Adams, 1976) and the Precambrian Brioverian sediments is exposed on the northern side of the bay. In 1871 three sphalerite-galena-carbonate veins were discovered on the foreshore. The veins cut the Brioverian sediments and were of variable length. The longest (approximately 180 m) was Lode No. 1 which had a trend of 300°, whilst the other two were less than 100 m long with a trend of 300° (Lode No. 2) and 275° (Lode No. 3). The width of all three was observed to be between 0.5 and 2.0 m. Good silver values for the galena were reported by Williams (1871) and independently by Ogier (1871), and the *British Press and Jersey Times* for November 1871 reported an assay of 49% lead and 7% silver for the ore. Intermittent attempts were made to mine the veins during the 1870s.

The geology of the veins was described by Williams (1871) and Ogier (1871), and the mineralogy of Lode No. 3 was described by Teilhard de Chardin and Pelletier (1911). Mourant and Warren (1934) produced a sketch map of Le Pulec and revised the earlier geological and mineralogical descriptions. The most recent history and general description of the veins is given in an unpublished report by S. Howell deposited in the library of the Société Jersiaise (1977).

Only one of the veins, Lode No. 3, is still exposed; the other two were either removed by mining or lie beneath a metre of loose shingle.

Geology and field occurrence. The Brioverian sediments are thinly bedded, laminated mudstones and siltstones which are grey-black, hard, and well cleaved; however, they are brecciated and hornfelsed close to the granite contact (Henson, 1956), and are extensively but irregularly silicified. These irregular silicified lenses, 20-30 cm in diameter, are bleached and harder than their surrounding rocks, and are finely net-veined by quartz and minor sulphides. Larger pods, 50-100 cm in diameter, of coarse-grained milky quartz carry no significant sulphides.

A fault trending 275° extends from within the granite into the siltstones for approximately 50 m (Lode No. 3). The fault is barren in the granite, but contains a vein 10-70 cm thick of ferroan dolomite-sphalerite-galena mineralization when within the siltstones. These siltstones also carry numerous veinlets of dolomite and sphalerite, infilling joints and minor fractures up to 5 m either side of the vein.

Most of the vein displays rhythmic and often symmetrical crustification of the minerals inwards from the vein margins, but in some parts the mineralization has cemented blocks of brecciated wall rock.

Laboratory techniques. The mineralogy and paragenesis of the sulphide-containing bleached Brioverian sediments and the main lead-zinc-carbonate vein were studied using both transmitted and reflected light microscopy, supplemented by carbonate staining techniques and X-ray diffraction using the Debye–Scherrer camera. Electron-probe microanalysis was carried out using a Cambridge Microscan V instrument operated with an accelerating voltage of 15 kV. For each analysis three ten-second counts were taken, and the results averaged and corrected for background and dead time (Sweatman and Long, 1969). Further corrections were made by a computer using a program devised by Duncumb and Jones (1969). The radiations measured were Cu-K_α, Ag-L_α, Fe-K_α, Zn-K_α, As-K_α, S-K_α, Sb-L_α, and Pb-M_α and the standards used were the pure metals Cu, Sb, Ag, and Zn, and the compounds PbS, FeS_2, and FeAsS (the Asp_{200} arsenopyrite standard of Kretschmar and Scott, 1976).

The Brioverian sediments. The unbleached siltstones contain minor quantities of acicular antase and rutile, zircon, pyrite, and chalcopyrite as their heavy mineral suite. The bleached siltstones are a fine-grained quartz–white mica–chlorite–carbonate rock that contains minor quantities of zircon, magnetite, oxidized ilmenite laths, anatase, and rutile, and 10–20 μm hematite laths. The rock is extensively net-veined by quartz, or quartz and ferroan dolomite, or by ferroan dolomite and sulphides.

There are three distinct assemblages of the sulphides, and their paragenesis is shown in fig. 1. The earliest is of long tabular clusters of marcasite up to 700 × 200 μm, with a distinctive rhombic fracture, and composed of numerous smaller 60 × 10 μm laths which display euhedral rhombic terminations. Qualitative electron-probe microanalysis has shown the marcasite not to contain significant Co, Ni, or As, unlike marcasite of similar appearance from the north Pennines (Ixer, Stanley, and Vaughan, 1979). The marcasite encloses euhedral to subhedral pyrite grains (5–20 μm in diameter), which in turn enclose small grains of pyrrhotine (2–5 μm in diameter). The marcasite laths are cemented by 5–15-μm-wide rims of chalcopyrite or by minor amounts of galena and sphalerite.

Surrounding the marcasite is a generation of coarse-grained (100–400 μm), skeletal or spongy, poorly crystalline pyrite, which typically displays 50-μm-wide zones of small non-opaque inclusions parallel to the grain edges.

The final assemblage is of euhedral, optically zoned rhombic (50 μm) or tabular (100–200 μm in length) arsenopyrite crystals, accompanied by minor amounts of pyrrhotine, chalcopyrite, sphalerite, galena, and traces of molybdenite. The arsenopyrite surrounds the earlier marcasite and pyrite, but is itself fractured and cemented and partially replaced by chalcopyrite and galena.

The silicified Brioverian sediments and accompanying mineralization occur within the brecciated ore of the main vein and are cemented by ferroan dolomite and sphalerite.

Main vein. The earliest and most extensive mineralization consists of an iron-poor sphalerite that crystallized slightly before and also simultaneously with coarse-grained ferroan dolomite and minor quartz. Both the sphalerite and dolomite are veined and partially replaced by euhedral quartz accompanied by polymetallic mineralization and chlorite. The polymetallic mineralization occurs in three forms: as coarse-grained intergrowths enclosing the main sphalerite and consisting of galena, sphalerite, chalcopyrite, and quartz, accompanied by lesser amounts of tetrahedrite, native antimony, and bournonite; as fine-grained intergrowths of chalcopyrite, cubanite, and galena, with minor tetrahedrite, native antimony, and bournonite, within narrow quartz veins cutting the ferroan dolomite; and as mixed sulphides and sulphosalts cross-cutting the main sphalerite but without significant amounts of quartz. Later veins of ferroan calcite, and calcite and fine-grained quartz vug-infillings within the ferroan dolomite are barren of sulphides.

The opaque-mineral assemblage of the main vein in its proposed paragenetic sequence is shown in fig. 1. The earliest and most abundant sulphide is an iron-poor sphalerite containing less than 6.4 mole% FeS (Table I). It displays characteristic light-yellow internal reflections, extensive twinning which is displayed by its internal reflections, and slight colour zoning. At its margins are 30-μm-wide zones of 2–3-μm-diameter chalcopyrite inclusions together with rods (5 × 1 μm) of tetrahedrite (the latter confirmed by qualitative electron-probe microanalysis). The sphalerite is extensively replaced by quartz and by minerals formed during the coarse-grained polymetallic mineralization, and fractures within the sphalerite are infilled by the same polymetallic mineralization but without accompanying quartz. A later generation of sphalerite 50–250 μm in diameter is also iron-poor, but carries orientated chalcopyrite inclusions. It is intergrown with galena, chalcopyrite, and quartz.

Euhedral to subhedral crystals of pyrite, containing framboidal or colloform pyrite cores or cores of very finely intergrown pyrite and marcasite, also contain small (2 μm in diameter) pyrrhotine inclusions and are found immediately surrounding the main sphalerite or as inclusions in galena, chalcopyrite, or later sphalerite. Rare but discrete (5–10 μm) crystals of pyrite, which display slight colour and hardness variations, occur within the ferroan dolomite, and thin veinlets of shattered pyrite cemented by galena are also present.

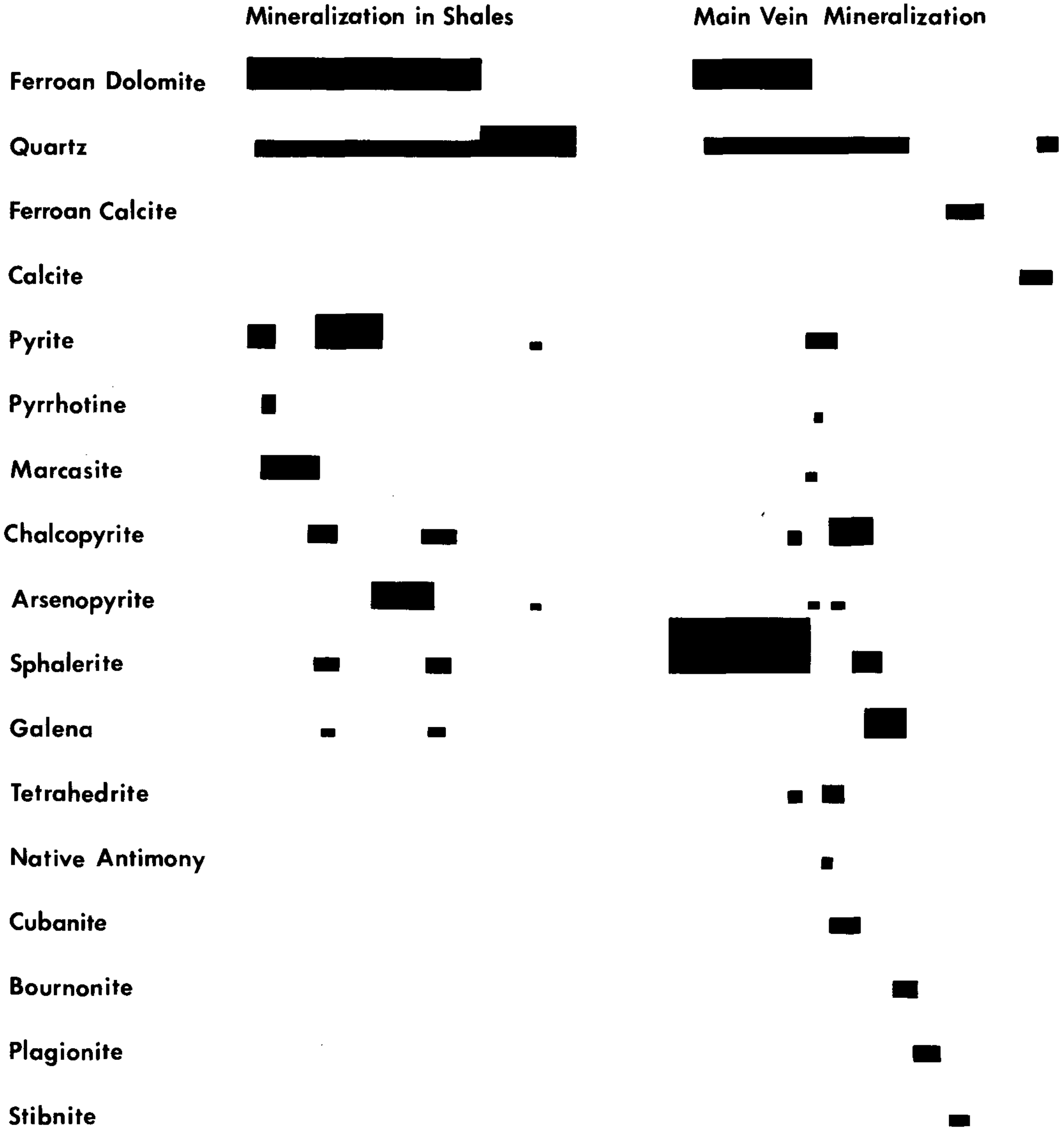

FIG. 1. Paragenetic diagram for mineralization at Le Pulec.

Native antimony is present in all three polymetallic mineralization types and is intergrown with tetrahedrite, cubanite, galena, chalcopyrite, and bournonite, or forms small discrete anhedral or tabular grains (2–10 μm in length) within coarsely crystalline galena. Minor amounts of optically zoned arsenopyrite are associated with native antimony within galena and chalcopyrite, or are enclosed by poorly crystalline pyrite, or occur as rhombs up to 10 μm in dolomite where they are enclosed by plagionite or stibnite. Electron-microprobe analyses (Table I) showed slight compositional zoning of the arsenopyrite. Tetrahedrite in trace amounts is found as inclusions in the main sphalerite, and as small grains intergrown with and surrounding native antimony within the chalcopyrite–cubanite–galena–quartz veins cutting ferroan dolomite. Larger grains up to 40 μm in diameter occur within coarse galena crystals around the main sphalerite. The tetrahedrite is accompanied by native antimony and cubanite, and typically occurs as rounded grains which are

TABLE I. *Electron microprobe data*

	Wt %								
Mineral species	Cu	Ag	Fe	Zn	Sb	As	S	Total	
Tetrahedrite	21.8	16.7	2.0	5.6	29.1	n.d.	22.9	98.1	$(Cu_{0.68}Ag_{0.32})_{9.1}\ (Fe_{0.30}Zn_{0.70})_{2.3}\ Sb_{4.4}\ S_{13.2}$
"	29.2	10.5	3.8	2.8	29.0	n.d.	23.0	98.3	$(Cu_{0.83}Ag_{0.17})_{10.0}(Fe_{0.61}Zn_{0.39})_{1.9}\ Sb_{4.3}\ S_{12.8}$
"	23.7	20.1	3.6	2.8	26.7	n.d.	21.7	98.6	$(Cu_{0.67}Ag_{0.33})_{10.4}(Fe_{0.61}Zn_{0.39})_{2.0}\ Sb_{4.1}\ S_{12.6}$
"	29.8	11.5	4.1	2.4	29.4	n.d.	23.1	100.3	$(Cu_{0.82}Ag_{0.18})_{10.1}(Fe_{0.65}Zn_{0.35})_{2.0}\ Sb_{4.3}\ S_{12.7}$
"	30.1	9.1	3.9	2.6	29.0	n.d.	23.3	98.0	$(Cu_{0.85}Ag_{0.15})_{9.9}\ (Fe_{0.63}Zn_{0.37})_{2.0}\ Sb_{4.2}\ S_{12.9}$
"	25.4	17.4	3.3	2.7	28.7	n.d.	22.7	100.2	$(Cu_{0.71}Ag_{0.29})_{10.1}(Fe_{0.59}Zn_{0.41})_{1.8}\ Sb_{4.3}\ S_{12.8}$ Formulae calculated on the basis of atomic ratios to Σ (atoms) = 29. Pb and As not detected
Sphalerite	—	—	3.7	63.0	—	—	32.8	99.5	6.4 mole % FeS coexisting with cpy.
"	—	—	2.9	63.2	—	—	32.7	98.8	5.2 mole % FeS coexisting with galena.
Cubanite	23.2	—	40.3	—	—	—	34.9	98.4	$Cu_{1.01}Fe_{1.99}S_3$
Arsenopyrite	—	—	33.9	—	—	44.2	21.1	99.2	marginal arsenopyrite 31.8 At % As
"	—	—	34.7	—	—	44.8	20.8	100.3	core arsenopyrite 32.0 At % As
Stibnite	—	—	—	—	71.8	—	26.5	98.3	
"	—	—	—	—	72.3	—	26.6	98.9	
				Cu	Pb	Sb	S		
Bournonite				13.3	43.3	25.4	17.9	99.9	
"				13.0	43.2	25.5	18.5	100.2	

All analyses from specimen J4 except arsenopyrite (J7).

extensively replaced by chalcopyrite, galena, and especially by bournonite. Colour zoning in the tetrahedrite is seen, with grey-green cores and lilac-brown margins, which may reflect compositional zoning or incipient alteration. A dark-green tetrahedrite which has a composition similar to that of freibergite (semiquantitative analysis showed it to have approximately 40 wt % silver) is also present in very minor amounts. The more common tetrahedrite is less argentian, with silver contents varying from 9.1 to 20.1 wt % silver, and is accompanied by minor amounts of zinc (2.4–5.6 wt %) and iron (2.0–4.1 wt %) (Table I). The presence of cubanite was confirmed by electron-microprobe analysis (Table I). It occurs as laths (10 × 2 μm) around chalcopyrite, or forms lamellae within it, accompanied by minor quantities of pyrite. It is more characteristic of the chalcopyrite-cubanite-galena-quartz veins than of the coarser sulphides and quartz that surround the main sphalerite.

Chalcopyrite, the third most abundant sulphide, forms fine 'exsolution' blebs and very fine veinlets in the main sphalerite; or is intergrown with cubanite in the small quartz-polymetallic veins; or occurs as relatively large (up to 600 μm in diameter) anhedral grains intergrown with galena, later sphalerite and euhedral quartz. These larger grains have growth zones that contain numerous anhedral inclusions of tetrahedrite, galena, and sphalerite of 20–30 μm diameter, and smaller inclusions of cubanite, pyrite, and native antimony.

Galena, the second most common sulphide, is the last primary sulphide in the chalcopyrite-cubanite-galena-quartz vein assemblage. Within the coarser assemblage it forms subhedral crystals up to 800 μm across. Galena replaces tetrahedrite, arsenopyrite, and pyrite, but is itself extensively replaced by plagionite and bournonite.

Bournonite, which displays its characteristic parquet twinning, replaces both tetrahedrite and galena, forming rounded aggregates up to 200 μm in diameter within galena, and thin 5–10-μm rims about galena where it is associated with plagionite. Plagionite, displaying its characteristic red internal reflections, forms small euhedral rhombs 5–20 μm in length that overgrow chalcopyrite, galena, and arsenopyrite.

Minor amounts of stibnite, as discrete, lanceolate crystals measuring 20 × 2 μm, often in sheaf-like aggregates, are found in the ferroan dolomite where they surround arsenopyrite, galena, chalcopyrite, and bournonite.

Secondary minerals are of only minor importance. Fibrous and bladed covelline replaces chalcopyrite, in association with minor amounts of bornite and blue copper sulphides. 'Blaubleibender covelline' replaces chalcopyrite, galena, tetrahedrite, and bournonite.

Discussion and conclusions. The Brioverian sediments at Le Pulec have undergone two distinct episodes of mineralization, both of which were polyphase. The earlier involved the introduction of pyrite-pyrrhotine-marcasite, and later of arsenopyrite, chalcopyrite, and sphalerite accompanied by silicification and dolomitization of the sediments. Although there are some mineralogical differences (notably the absence of hematite), the mineralization is similar to other mineral occurrences in Jersey, and especially to the mineralization found within small carbonate veins cutting the North-West granite at Douet de la Mer (Ixer, 1980).

The main vein at Le Pulec consists of sphalerite and ferroan dolomite, followed by polymetallic mineralization from fluids rich in lead, copper, iron, silver, and antimony. This mineral assemblage appears to be unique in Jersey both for the amount of argentian tetrahedrite and the presence of other antimony-bearing minerals. The only other antimony-bearing minerals recorded from Jersey, bindheimite and jamesonite, are from quartz veins from the nearby L'Etacq granite quarries (Mourant, 1978).

Antimony- (and silver-) bearing mineralization occurs, however, elsewhere in the Channel Islands, and work currently in progress shows that the ores from the Hope Silver Mine on the island of Sark also contain a number of antimony minerals in addition to the antimony-bearing plumbian tennantite described by Bishop, Criddle, and Clark (1977). It is hoped that future studies will allow a comparison of the antimony-bearing mineral occurrences of the Channel Islands with those found within the Armorican Massif described by Chauris (1977).

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REFERENCES

Adams (C. J. D.), 1976. *J. Geol. Soc. Lond.* **132,** 233–50.
Bishop (A. C.), Criddle (A. J.), and Clark (A. M.), 1977. *Mineral. Mag.* **41,** 59–63.
Chauris (L.), 1977. *Mineral. Deposita,* **12,** 353–71.
Duncumb (P.) and Jones (E. M.), 1969. Tube Invest. Res. Lab. Report No. 260.
Henson (F. A.), 1956. *Geol. Mag.* **93,** 473–84.
Howell (S.), 1977. Unpublished report. Société Jersiaise.
Ixer (R. A.), 1980. *Ann. Bull. Soc. Jersiaise.* In press.
——Stanley (C. J.), and Vaughan (D. J.), 1979. *Mineral. Mag.* **43,** 389–95.
Kretschmar (U.) and Scott (S. D.), 1976. *Canad. Mineral.* **14,** 364–86.
Mourant (A. E.), 1978. The minerals of Jersey. Société Jersiaise. 24 pp.
——and Warren (J. P.), 1934. *Rep. Trans. Soc. Guernes.* **12,** 73–88.
Ogier (E. F.), 1871. *Rapport sur les mines de plomb du Pulec.* Jersey. 8 pp.
Sweatman (T. R.) and Long (J. V. P.), 1969. *J. Petrol.* **10,** 332–79.
Teilhard de Chardin (P.) and Pelletier (F.), 1911. *Ann. Bull. Soc. Jersiaise.* **7,** 99–111.
Williams (B.), 1871. *Report on the Jersey silver-lead mine.* Jersey. 4 pp.

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ADDENDUM

This appears to be the first authentic occurrence of native antimony in the U.K. Garby (1848) referred to its doubtful occurrence in the antimony mines of north Cornwall; recently (Stanley, in prep.), it has been identified in specimens from the Pengenna Mine, Cornwall, and also from Hannaford, Devon. Native antimony commonly occurs as inclusions ($< 5\ \mu m$) in galena from Lake District localities (Stanley, 1979; Stanley and Vaughan, in press).

REFERENCES

Garby (J.), 1848. *Trans. R. Geol. Soc. Cornwall,* **7,** 72–92.
Stanley (C. J.), 1979. Unpubl. Ph.D. thesis, University of Aston in Birmingham.