



Title	Enhancing current understanding of Irish Zn-Pb mineralization: a closer look at the Island Pod orebody, Lisheen deposit
Authors(s)	Doran, Aileen, Menuge, Julian, Hollis, Steven P., Güven, John, Dennis, Paul
Publication date	2017-08-23
Publication information	Doran, Aileen, Julian Menuge, Steven P. Hollis, John Güven, and Paul Dennis. "Enhancing Current Understanding of Irish Zn-Pb Mineralization: A Closer Look at the Island Pod Orebody, Lisheen Deposit." Society for Geology Applied to Mineral Deposits, August 23, 2017.
Conference details	SGA Quebec 2017 14th Biennial Meeting, Quebec City, Canada, August 20-23 2017
Publisher	Society for Geology Applied to Mineral Deposits
Item record/more information	http://hdl.handle.net/10197/9362

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Enhancing understanding of Irish Zn-Pb mineralization: a closer look at the Island Pod orebody, Lisheen deposit

Aileen L. Doran, Julian F. Menuge, Steve P. Hollis, & John Güven

Irish Centre for Research in Applied Geosciences (iCRAG) & University College Dublin, Ireland

Paul F. Dennis

University of East Anglia, England

Abstract. Irish-type deposits are a series of Zn-Pb orebodies, formed from the carbonate replacement of Lower Carboniferous limestone, triggered primarily by fluid mixing. Current understanding of the complex fluid flow and mixing dynamics associated with mineralization is limited. By applying clumped O-C isotope analysis to these deposits, these processes can be constrained. Preliminary paragenetic studies of the Island Pod orebody (0.4 Mt @ 20% Zn & 1.6% Pb) have yielded textural evidence for early fluid mixing of sulphide-rich fluids, in a quiescent, far-from equilibrium environment, resulting in the rapid precipitation of dendritic galena and intergrowths of dolomite and sphalerite. Initial clumped O-C analysis has revealed temperatures of 100-170°C for hanging-wall white matrix breccias that accompanied ore formation. This technique will be used to constrain temperature variations across the orebody, thus yielding information on how the fluid evolved as precipitation continued. A more detailed paragenetic study is underway and will form the foundation of future clumped O-C isotope and Zn-Cu-S isotope analysis.

1 Introduction

Irish-type deposits have produced globally significant quantities of zinc (Ashton et al. 2015). Since the 1960s there have been five such Zn-Pb orebodies mined in Ireland and over twenty sub-economic prospects discovered (Fig. 1). With the closure of the Lisheen mine in 2015, the only operational mine in Ireland is at Navan (Fig. 1).

Irish-type Zn-Pb deposits are a series of stratabound orebodies, which are carbonate-hosted and structurally controlled. Mineralization is typically found adjacent to normal faults. Irish Zn-Pb deposits formed from carbonate replacement of Lower Carboniferous limestone, when metal-bearing, hydrothermal fluids (up to 200°C) ascended on normal faults to mix with sinking, cooler (<50°C) hypersaline brines carrying bacteriogenically reduced dissolved sulphide (Wilkinson et al. 2005). The Lower Carboniferous marine limestones conformably overlie non-marine Devonian-Carboniferous rocks, with metals most likely sourced from the Lower Paleozoic basement beneath the deposits (Walshaw et al. 2006).

Many of the complex processes involved in the formation of these deposits are still poorly understood. Good progress has been made with understanding the composition of fluids involved in mineralization (Wilkinson et al. 2005). However, little has been done on identifying possible geochemical or isotopic haloes and understanding fluid processes involved in ore formation.

We aim to increase the understanding of these Zn-Pb deposits through the application of clumped O-C isotope techniques.

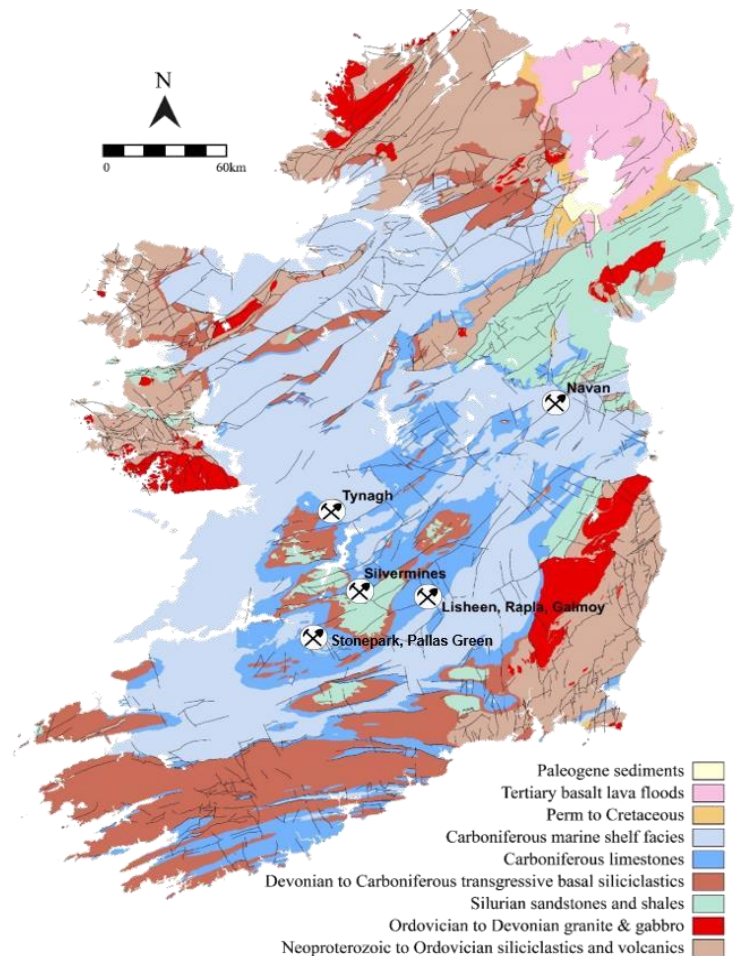


Figure 1. A simplified geological map of Ireland (Geological Survey Ireland, Bedrock 1:500,000). Locations of significant mined Zn-Pb deposits in Ireland have been highlighted, including the recently closed Lisheen deposit, along with the Stonepark/Pallas Green prospect.

2 Island Pod orebody, Lisheen

The Lisheen deposit (23 Mt @ 13.3% Zn & 2.3% Pb; Fig. 1) consists of several discrete, stratabound orebodies that are strongly controlled by an extensional, left-stepping, ramp-relay fault array to the south (Fig. 2). The Island Pod (0.4 Mt @ 20% Zn & 1.6% Pb) is a small, satellite, body of

high-grade mineralisation located approximately 900 m to the northeast of the Derryville Zone orebody (Fig. 2). It was first intersected by drilling in 2005 but only properly evaluated by drilling in 2011.

The authors are initially focusing on the Island Pod orebody, where limited work has been carried out on understanding the fluid regime associated with ore deposition. We present the first detailed paragenetic study of this orebody, incorporating detailed optical, SEM and cathodoluminescence work.

When compared to the other orezones at Lisheen (Main Zone, Derryville, Bog Zone; Fig. 2), the Island Pod exhibits some unique features, including;

- 1) weak extensional structural control on the highest quality and thickest ore;
- 2) most mineralization is located some 20 m above the base of the Lower Carboniferous Waulsortian Formation host rock, rather than, as is typical, being at the base of the Waulsortian Formation in contact with the older Argillaceous Bioclastic Limestone (Hitzman et al. 2002);
- 3) there is rapid, lateral variation on a small (< 10 m) scale, where adjacent boreholes can have a zinc concentration difference of ~ 40 %;
- 4) mineralization is not obviously associated with the replacement of hydrothermal black matrix breccias, as observed elsewhere in Irish Waulsortian-hosted deposits (Hitzman et al. 2002).

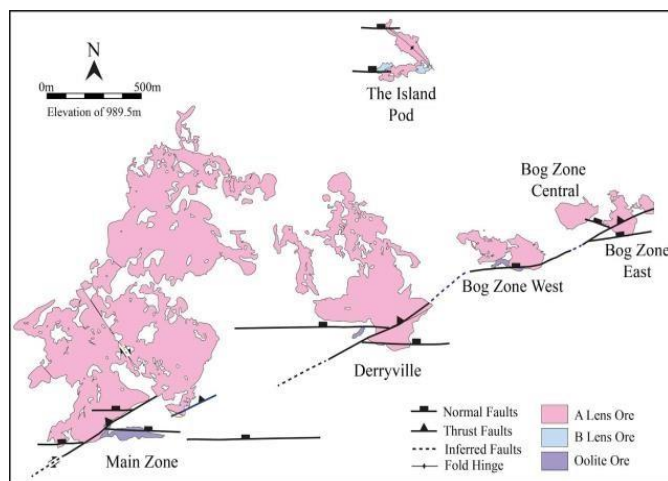


Figure 2. Location of Island Pod orebody relative to rest of Lisheen's mineralized deposits (Main Zone, Derryville, Bog Zone). Lisheen is in the southern midlands of Ireland (Fig. 1). The left-stepping, ramp-relay fault array and main structural features associated with the Island Pod orebody are shown (modified after Kyne et al. 2017).

3 Textural studies and paragenesis

Paragenetic studies of the Island Pod orebody have been carried out through detailed optical and SEM petrography of a restricted number of samples from the subeconomic

halo laterally surrounding the main mineralization. This study has identified a sulphide mineralogy of pyrite, sphalerite, galena for the available samples.

Preliminary textural studies of the main sulphide lenses have revealed distinctive textures such as dendritic galena, associated with dolomite and colloform sphalerite (Fig. 3), and intergrowths of colloform sphalerite and dolomite (Fig. 4). These textures suggest that as the composition of the mineralizing fluid evolved over time, the system moved towards equilibrium, allowing precipitation rates to slow, causing dendritic and intergrowth textures to cease, and more equant crystals of galena to form. Based on the textures observed within the Island Pod subeconomic halo, an initial paragenesis can be determined; colloform sphalerite/pyrite → dendritic galena → sphalerite/dolomite intergrowths → coarse grained galena → rhombohedral dolomite associated with a later/non-euhedral pyrite. Very fine-grained pyrite, possibly framboidal, was also observed associated with colloform sphalerite.

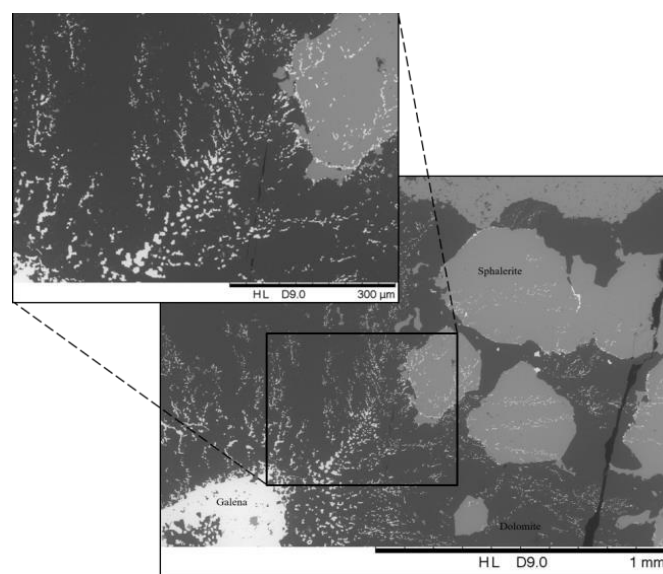


Figure 3. SEM image of branching galena. The branching galena can be seen interacting with dolomite and sphalerite. Coarse, later galena is also observed here (bottom, left corner).

At higher stratigraphic levels in the sub economic halo, stringer mineralization exhibits a simpler paragenesis; coarse, euhedral pyrite → three generations of carbonate → disseminated sphalerite → disseminated pyrite. Galena is not observed and sphalerite is only present in minor, disseminated amounts. Coarse, early pyrite is followed by at least three generations of carbonate, ranging from fine to coarse grained. Late, disseminated sphalerite, followed by dispersed pyrite is also seen, typically associated with finegrained carbonate veins. This may represent a residual fluid that was devoid of dissolved sulphide.

In other Zn-Pb deposits, dendritic and colloform sphalerite intergrowth textures have been interpreted as representing early, rapid sulphide precipitation events

resulting from supersaturated fluid in a far-from-equilibrium, quiescent environment (Fowler and L'Heureux 1996; Wilkinson et al. 2005). Specifically, Wilkinson et al. (2005) discussed these textures in relation to the main ore stage in the Main, Derryville and Bog Zones at Lisheen (Fig. 2). They interpreted these textures as resulting from rapid crystallization from a sulphide supersaturated fluid, due to fluid mixing.

In order to constrain a more representative paragenesis, a detailed and thorough investigation is under way based on a new suite of samples (~130) collected from the Island Pod orebody and its surrounding zones of sub-economic mineralization.

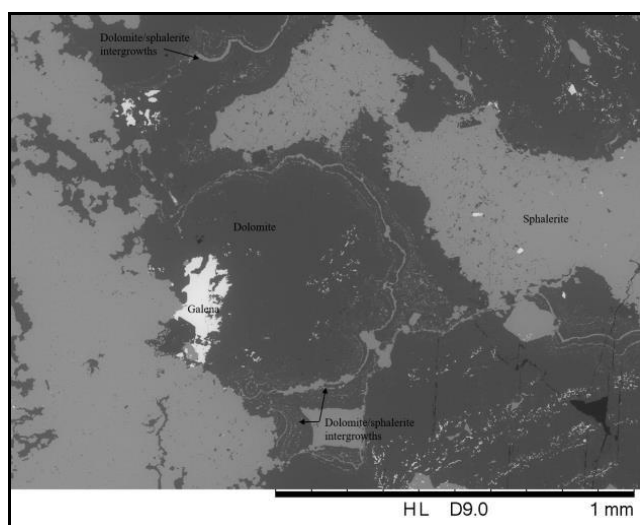


Figure 4. SEM image displaying intergrowths of sphalerite and dolomite, the sphalerite often displaying a colloform texture.

4 Clumped O-C isotope and fluid inclusion study

Previous thermometry studies of carbonates have been based on $\delta^{18}\text{O}$ measurements of carbonate minerals (Huntington et al. 2011). However, this method is dependent on both the crystallization temperature and the isotopic composition of the fluid(s).

In carbonate minerals, the heavy isotopes of O and C (^{13}C , ^{18}O) are seen to 'clump' or bond more frequently to each other than if bonding frequency was random (Wang et al. 2004). The extent of this 'clumping' is temperature dependent, but importantly is independent of fluid isotope composition and chemistry of the carbonate minerals. Thus, clumped O-C isotope analysis offers a novel and reliable method for determining the temperature of fluids associated with Irish Zn-Pb formation (Hollis et al. 2017, this volume).

This method is being used to constrain fluid flow and mixing processes, along with temperature variations across orebodies.

Preliminary clumped O-C isotope data from the Island Pod orebody have revealed temperatures of 100-170°C for hanging-wall white matrix breccias and a more extensive

programme of clumped O-C isotope analysis of carbonate samples from the Island Pod deposit is planned. All samples are being characterized prior to clumped isotope analysis to determine the relative timing of carbonate precipitation to mineralization.

We will present new data from across the Island Pod orebody, for all main phases of carbonate formation. Complimentary fluid inclusion data obtained will also be presented and will be the first fluid inclusion constraints from the Island Pod. We will establish whether ore forming processes were similar to those operating elsewhere in the Irish orefield.

5 Conclusions

Preliminary paragenetic work on the Island Pod orebody suggests that an early, rapid precipitation event occurred, which resulted in dendritic galena and intergrowths of sphalerite and dolomite. These textures have also given an indication of the local direction of crystal growth, which may relate to fluid flow direction. This early mineralization likely occurred in a calm, far-from equilibrium environment, from a sulphide supersaturated fluid, that resulted from early fluid mixing in the system. As the fluid composition evolved, due to changes in mineralization environment, including fluid composition and temperature changes, through new pulses of fluid to the system or/and crystallization of early sulphides altering the fluid chemistry, sulphide minerals precipitated as coarser and more equant crystals. Late, disseminated pyrite and sphalerite grains, often concentrated around carbonate veins, possibly highlight fluid conduits and the crystallization of residual fluid which contained minor sulphides.

Clumped O-C isotope analysis will advance preliminary deposit understanding provided by detailed paragenetic studies. Initial clumped data has revealed temperatures of 100-170°C for hanging-wall white matrix breccias. This technique is being used to constrain data on the fluid regime that led to mineralization in the Island Pod orebody, including fluid flow and mixing processes. Using the clumped isotopic techniques, temperature variations from across the Island Pod will be determined for each carbonate generation, further enhancing our understanding of fluid processes in Irish-type deposits that are associated with Zn-Pb mineralization.

6 Future work

Future Zn-Cu-S isotope analysis of the different sulphide generations will provide new insights into the dynamic fluid mixing processes, complementing the clumped O-C data obtained from carbonate analysis. This data will then be applied to the larger scale to enhance understanding of the fluid regime responsible for the investigated deposits. The genetic relationships between economic deposits and their sub-economic haloes will also be investigated.

Acknowledgements

The authors thank Roisin Kyne, Koen Torremans, John Conneally, Rob Doyle and Oakley Turner for help sampling, and for many thought provoking discussions on the geology of the Lisheen deposit. Vedanta Resources are thanked for access to the Lisheen mine and drillcore. This publication has emanated from research conducted with the financial support of Science Foundation Ireland (SFI) under Grant Number 13/RC/2092 and co-funded under the European Regional Development Fund.

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