Timing of mineralization at the Navan Zn-Pb deposit: A post-Arundian age for Irish mineralization

Wendy M. Peace
Malcolm W. Wallace
School of Earth Sciences, University of Melbourne, Victoria 3010, Australia

ABSTRACT

Navan is the largest of the Irish Zn-Pb deposits and contains some of the most important evidence for the inferred early timing of mineralization in Ireland (clasts of ore above a middle Carboniferous erosion surface). We have examined diagenetic fabrics within the main ore (pale beds) and the overlying erosion surface (Boulder Conglomerate) in order to determine the timing of mineralization. This diagenetic analysis (and particularly the presence of pre-mineralization dolomite in the Boulder Conglomerate) has revealed that all of the mineralization postdates the erosion surface and therefore must be post-Arundian (345 Ma) in age. Furthermore, the Navan mineralization must be entirely epigenetic in origin (i.e., similar to Mississippi Valley–type deposits) and is likely to be Holkerian (343 Ma) in age or younger. This conclusion disagrees with the previous model of at least partially syngenetic mineralization, and has important implications for the age of other deposits in Ireland and the nature of "Irish-type" deposits in general.

Keywords: Irish-type, Navan, epigenetic, zinc.

INTRODUCTION

The Irish Zn-Pb deposits are a genetic intermediate between ore deposits of epigenetic Mississippi Valley type and synsedimentary (sedimentary exhalative) type (e.g., Hitzman and Beaty, 1996). At more than 69 Mt, the Navan deposit is by far the largest of the carbonate-hosted Zn-Pb deposits of the Irish Midlands. Furthermore, Navan has been documented as having some of the most crucial evidence for the relatively early diagenetic timing of Zn-Pb mineralization in Ireland. At Navan, the principal argument for a synsedimentary to early diagenetic origin is the presence of reworked clasts of ore within the boulder conglomerate of late Chadian–early Arundian (345 Ma) age. Therefore, a pre-Arundian age is indicated for the bulk of mineralization (Ashton et al., 1986, 1992).

In this paper we examine the timing of sulfide mineralization at Navan by relating the mineralization to the diagenetic and burial history of the host succession. We suggest that Navan is a completely epigenetic deposit that postdates the Arundian boulder conglomerate and overlying upper dark limestones, indicating a much younger age for mineralization than has previously been suggested.

GEOLOGY OF THE NAVAN DEPOSIT

The Navan Zn-Pb orebody is located 1 km northwest of Navan, County Meath, (~50 km northwest of Dublin, Fig. 1). Mineralization largely occurs as a series of stratabound lenses within a shallow-water carbonate sequence of early Carboniferous (Courceyan) (363 Ma) age known as the pale beds (Philcox, 1984). In the mine area, deformed lower Paleozoic rocks are unconformably overlain by a progressively deepening carbonate-dominated Courceyan succession consisting of the Navan group, argillaceous bioclastic limestone, and Waulsortian limestone (Fig. 2).

The Navan Group consists of five units: the red beds, laminated beds, muddy limestone, pale beds, and shaley pale beds (Philcox, 1984). The basal red beds and overlying laminated beds are composed predominantly of siliciclastics, the overlying muddy limestone marking the transition to dominantly carbonate sedimentation. The muddy limestone passes into the pale beds, host to >97% of the ore. The pale beds are composed of a sequence of progressively deepening sediments, with micritic mudstones and wackestones at the base, and grainstones, wackestones, packstones, and occasional sandstones in the upper half. The pale beds are overlain by the shaley pales (shales and carbonates). Overlying the shaley pales are the argillaceous bioclastic limestone (shaley crinoidal limestones) and Waulsortian limestone (dominantly micritic mud mounds).

A southward-sloping submarine erosion surface of pre-Arundian age (345 Ma) has cut down as far as the pale beds in the mine area. This surface is overlain by a series of debris-flow breccia-conglomerates termed the boulder conglomerate (Philcox, 1989), which hosts ~3% of the ore at Navan (the conglomerate group ore). The boulder conglomerate varies from clast to matrix supported and contains sand- to boulder-sized clasts of pale beds through to Waulsortian limestone. The boulder conglomerate is overlain by a sequence of turbiditic limestones and shales of Chadian (350 Ma) to Arundian age known as the upper dark limestones.

METHODS

The upper pale beds (the upper ~60 m of the pale beds) were logged, and samples were taken from >70 mine and exploration drill cores from the mine lease. From these samples, >200 thin sections of the upper pale beds and the overlying boulder conglomerate were produced. These were used to determine the cathodoluminescent (CL) cement stratigraphy of the upper pale beds and the boulder conglomerate and the timing of base-metal mineralization relative to this stratigraphy. Cathodoluminescent microscopy of polished thin sections was performed using a Nuclide ELM-2A cathodoluminoscope mounted on a Wild M400 photomicroscope. The thin sections were placed within a 50 milliTorr vacuum and bombarded by an electron beam set at 9 kV with a current of 60–70 µA.

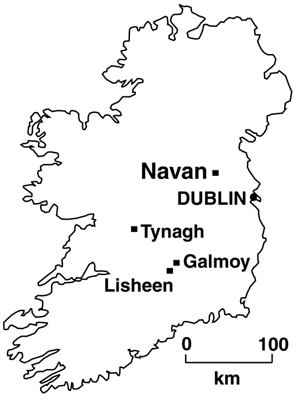
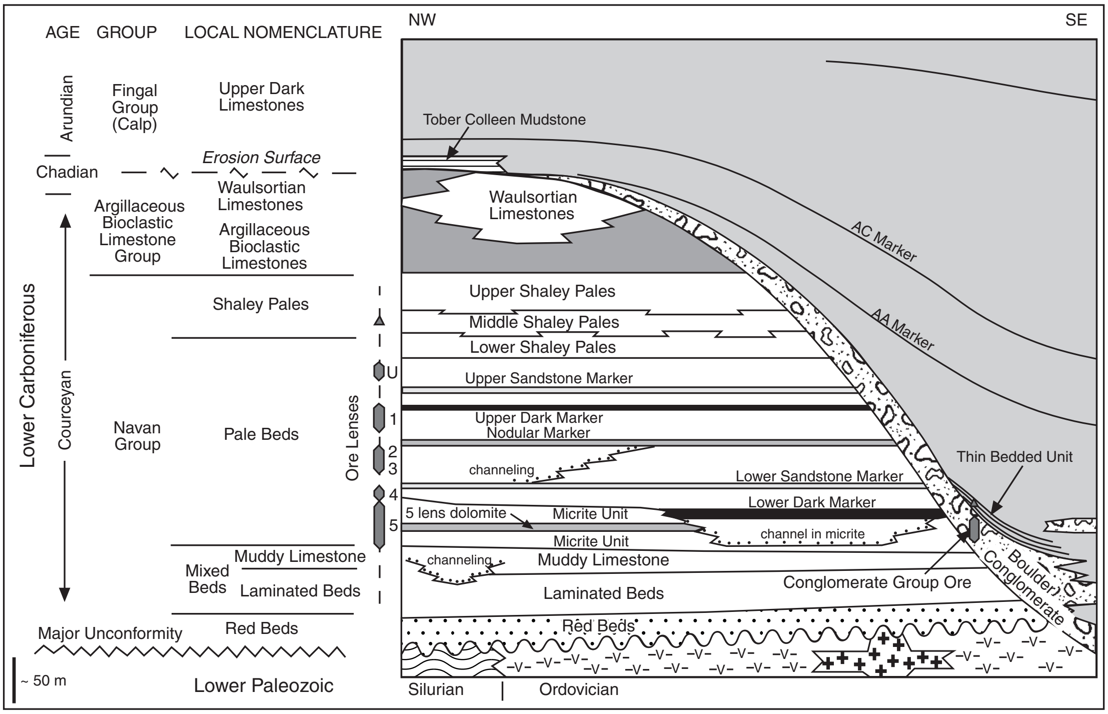


Figure 1. Locality map of Ireland showing location of Navan and several other Irish-type deposits.

Figure 2. Stratigraphic sequence in Navan mine area, including marker horizons to delineate ore lenses (from Ashton, 1995).



UPPER PALE BEDS DIAGENESIS

A regionally consistent cementation sequence is present around the Navan region (Fig. 3). Initial cements are composed of fine isopachous rinds of inclusion-rich calcite that are nonluminescent with dully luminescent rims. These isopachous calcite cements are typical of marine cements as described by James and Choquette (1984).

The isopachous marine calcite is overlain by coarser, equant calcite cements that are well zoned in CL. These equant calcite cements are interpreted as being of burial origin; they postdate several burial diagenetic features, including stylolites and physical and chemical compaction of grains, and fill moldic porosity and tectonic fractures (Peace, 1999). These equant calcite cements can be divided into premineralization (complexly zoned nonluminescent to dull-bright bands), synmineralization (bright), and postmineralization (dull to nonluminescent) phases. Dolomitization of the upper pale beds occurred prior to sulfide mineralization. The dolomite occurs as fine- to medium-grained pale gray euhedral rhombs that have a cloudy, nonluminescent to very dully luminescent core surrounded by a dully luminescent zone and a bright rim. The primary zonation may be partially or completely obliterated by dull red recrystallization, especially near sulfides.

Medium to coarsely crystalline white saddle dolomite overlies both the premineralization calcite and planar dolomite. The saddle dolomite is distinctive in CL, featuring completely black nonluminescence, save for a bright red band. Saddle dolomite crystallization was approximately synchronous with sulfide mineralization. Base-metal sulfides also overprint chemical compaction features such as grain-grain dissolution and stylolites. Where they occur within primary porosity, the base-metal sulfides and the associated saddle dolomite and brightly luminescent calcite cement precipitated after much of the porosity had already been occluded, indicating that the sulfides and attendant cements precipitated relatively late in the diagenetic history of the sequence.

BOULDER CONGLOMERATE DIAGENESIS

Fine-grained synsedimentary to early diagenetic framboidal pyrite is widespread within the boulder conglomerate. It typically occurs as fine, millimeter-scale laminae separated by similar (or larger) thicknesses of shale, but also occurs as thick, shale-poor laminated horizons to ~0.5 m thick.

Partial dolomitization of the boulder conglomerate is common where it directly overlies the upper pale beds. Fine to medium rhombs of planar dolomite occur within both the clasts and matrix of the boulder conglomerate. These rhombs show a zonation (nonluminescent core, dull zone, and bright rim) similar to that of the rhombs within the upper pale beds (Fig. 4) and are well-formed, euhedral to subhedral crystals with no evidence of abrasion or fracturing. Rhombs within clasts display the same zonation as rhombs within the matrix (Fig. 4B).

Several dolomitized clasts display evidence of intense compactional soft-sediment deformation such as elongation parallel to bedding, or warping around a larger, more solid clast. However, that the dolomite rhombs within these deformed clasts show no evidence of deformation or fracturing indicates that dolomitization postdates compaction in the boulder conglomerate. Similarly, where two clasts are in contact, planar dolomite rhombs are observed that overgrow the contact between the two. Fine-grained planar dolomite rhombs are also present growing within stylolites that crosscut clasts. All of these dolomite relationships indicate that the planar dolomite in the boulder conglomerate is a replacement phase of burial diagenetic origin, and is not detrital.

Saddle dolomite is widespread within the boulder conglomerate. This saddle dolomite has the same CL signature (black nonluminescence with a fine, bright red band) and relative timing (i.e., postdating planar dolomite and synchronous with base-metal sulfide mineralization) (Fig. 5) as the saddle dolomite within the upper pale beds. It occurs as both a coarse, space-filling cement and as overgrowths on replacive planar dolomite. Calcite cements in the boulder conglomerate form clear, equant syntaxial overgrowths on crinoid fragments. In CL, these cements are dully luminescent with a thin nonluminescent band near the crystal edge. Coarse, nonluminescent saddle dolomite overgrows these calcite crystals.

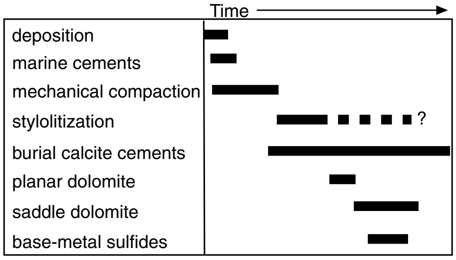


Figure 3. Relative timing of diagenetic processes in upper pale beds (from Peace, 1999).

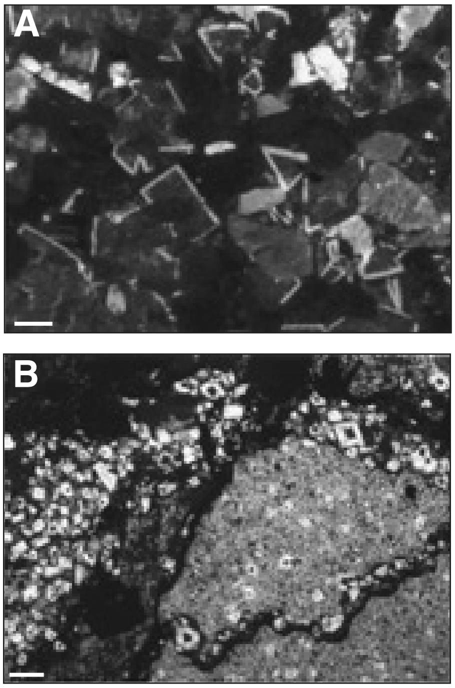


Figure 4. A: Zoned planar replacement dolomite from within upper pale beds (core N1348, 535.8 m). B: Zoned planar dolomite replacing both matrix and clasts within boulder conglomerate. Note that zonation of dolomite is same in clasts and matrix (core N1397, 725.8 m). Scale bar represents 0.1 mm in both photographs.

Although sulfide ore within the boulder conglomerate (the conglomerate group ore) tends to be more pyrite rich than the majority of the pale beds–hosted ore (Ashton et al., 1992), the general paragenetic sequence is the same. Nonluminescent saddle dolomite and barite are the dominant gangue minerals in both the pale beds and conglomerate group ores. Similarly, the final sulfide phase in the boulder conglomerate is a distinctive blocky yellow-brown sphalerite, the same as that found in the pale beds ore. Small dissolution cavities, complete with sulfide internal sediments and colloform sulfide cement–coated walls, identical to those within the upper pale beds, are also present within the conglomerate group ore.

Away from the conglomerate group ore, fine-grained sphalerite is concentrated along grain-grain pressure-solution contacts within clasts of crinoidal Waulsortian limestone. Rare anhedral sphalerite crystals have been observed within dissolution seams crosscutting carbonate clasts.

DISCUSSION: EVIDENCE FOR THE TIMING OF BASE-METAL MINERALIZATION

In both the pale beds and the boulder conglomerate, there is much evidence to indicate that base-metal sulfide mineralization is epigenetic. In the pale beds, mineralization postdates regional dolomitization, some stylolitization, and a considerable amount of burial calcite cementation. Minimum burial depths of 800 m have been suggested for macrostylolite formation in carbonate sequences elsewhere (Lind, 1993; Nicolaides and Wallace, 1997). The presence of stylolites overprinted by sulfides in the pale beds therefore suggests a considerable depth of burial prior to mineralization. The degree of burial cementation prior to mineralization is also suggestive of a deeply buried sequence.

The diagenesis of the boulder conglomerate is even more suggestive of an epigenetic origin for the base-metal sulfides. The boulder conglomerate has a diagenetic and mineralization sequence almost identical to that of the underlying pale beds, including planar replacement dolomite, a similar sulfide paragenesis, and the distinctive saddle dolomite. The most important observation on the boulder conglomerate diagenesis is the presence of planar replacement dolomite having a CL zonation similar to that in the underlying pale beds. In the pale beds, planar replacement dolomite predates base-metal mineralization. If the planar dolomite in the boulder conglomerate is the same generation as that in the immediately underlying pale beds, then the base-metal mineralization must postdate boulder conglomerate deposition.

It could be argued that the dolomite in the boulder conglomerate is of detrital origin (reworked from the underlying pale beds). However, dolomite rhombs in the boulder conglomerate are euhedral; there is no evidence of abrasion. Furthermore, there is strong evidence that the dolomite is of postcompactional replacement origin (e.g., undeformed replacement dolomite in strongly compacted clasts, identical zonation of replacement dolomite in matrix and clasts). A detrital origin for the dolomite can therefore be ruled out.

It might be argued that the planar dolomite and sulfides in the boulder conglomerate are not the same generation as their counterparts in the underlying pale beds; rather, two separate cycles of dolomitization and sulfide mineralization have occurred and only the second cycle affected the boulder conglomerate. However, the similarity in paragenesis suggests that dolomitization and mineralization within the pale beds and boulder conglomerate were the result of the same event. This interpretation is supported by the absence of a second generation of planar dolomite in the pale beds that postdates the sulfides.

Epigenetic mineralization within the boulder conglomerate is also supported by other diagenetic evidence. For example, saddle dolomite cement in the boulder conglomerate postdates a significant amount of equant calcite cement: this implies that some interval of time has passed between deposition of the boulder conglomerate and precipitation of the (mineralization phase) saddle dolomite.

From the preceding diagenetic evidence, we conclude that all of the base-metal mineralization at Navan must significantly postdate deposition of the boulder conglomerate. However, this conclusion conflicts with evidence documented by Ashton et al. (1992) of mineralized sulfide clasts within the boulder conglomerate. Many of these clasts feature broken rims of sphalerite, ruling out a purely replacement origin for these clasts. These have been interpreted as reworked clasts from the pale beds, and their presence within the conglomerate group ore has been taken as evidence that the pale beds ore was at least partly emplaced prior to formation of the boulder conglomerate.

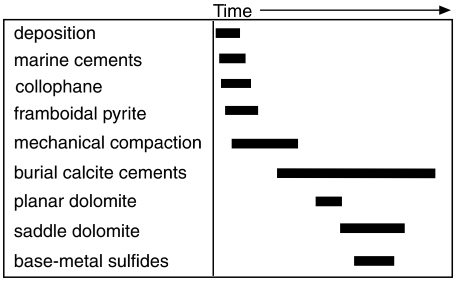


Figure 5. Relative timing of diagenetic processes in boulder conglomerate (from Peace, 1999).

We suggest that these mineralized clasts within the boulder conglomerate are not detrital in origin, but are contained within hydrothermal breccias, the result of brecciation during the mineralizing event that stoped upward from the underlying pale beds into the boulder conglomerate. Similar textures are also present within the pale beds ore (Peace, 1999). It would not be a simple matter to detect such hydrothermal brecciation within the boulder conglomerate (itself a breccia-conglomerate), and it is therefore not unusual that such hydrothermal brecciation has gone unrecognized.

The absence of mineralized clasts in the boulder conglomerate away from conglomerate group ore is also strongly suggestive of a postdepositional origin for the clasts. We can find no mineralized clasts (not even microscopic clasts) within unmineralized boulder conglomerate. The only sulfide present was disseminated sphalerite of clearly replacement origin. If the pale beds mineralization predated the boulder conglomerate, some clasts of reworked sulfides would be expected within the unmineralized boulder conglomerate.

Minor sulfide mineralization (predominantly fracture-filling sulfides) within the upper dark limestones, combined with the presence of an extensive trace element (Mn, As, Zn, and Pb) halo (Ashton et al., 1986), also suggests that mineralization postdates deposition of the boulder conglomerate and at least the lower section of the upper dark limestones.

A reconstruction of the burial history of the sequence (Fig. 6) indicates that the upper pale beds and boulder conglomerate were not buried to depths of 800 m until Holkerian (343 Ma) time. We suggest that the Holkerian is probably a reasonable estimate of the earliest possible age for mineralization at Navan (which would allow suffi-

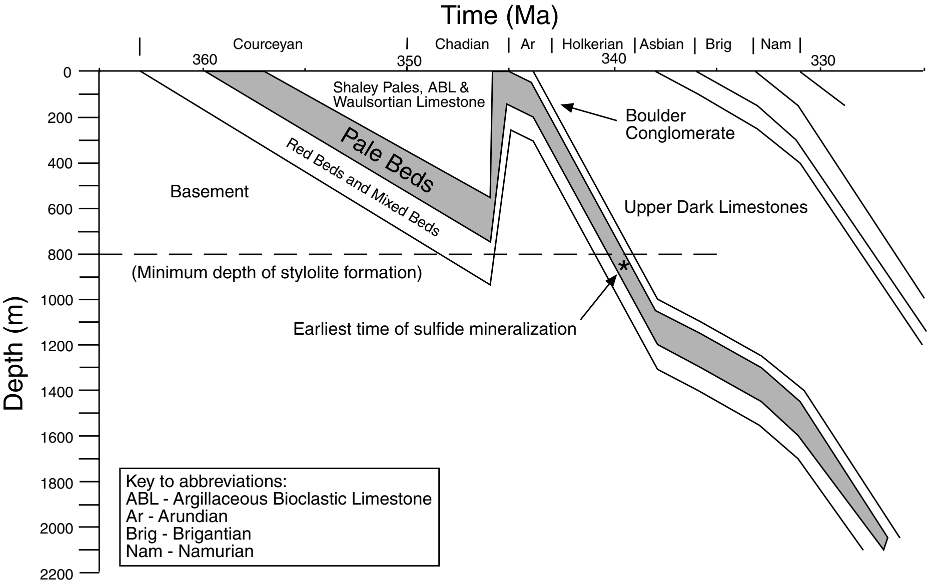


Figure 6. Burial-depth reconstruction of host sequence at Navan. Assigned unit thicknesses are based on data from Strogen et al. (1990), Somerville et al. (1992), Pickard et al. (1994), and Hitzman (1995). Geologic ages are from Harland et al. (1990).

cient burial prior to mineralization for the growth of stylolites and extensive burial cementation).

SUMMARY AND CONCLUSIONS

Diagenetic evidence from the pale beds and boulder conglomerate indicates that base-metal mineralization postdates the deposition of the boulder conglomerate. Therefore, the mineralization at Navan is entirely epigenetic in nature and most likely occurred in the Holkerian (343 Ma) or later. This timing has significant implications for the nature of Irish-type deposits in general and for models of deposit localization at Navan. The completely epigenetic nature of the Navan deposit suggests a similarity with Mississippi Valley–type mineralization. Furthermore, the presence of an impermeable cap (the boulder conglomerate and overlying upper dark limestone) that cuts down into the pale beds may be an important hydrogeologic factor in localizing mineralization.

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