Llyn Du Bach Complex

[SH 657 341], [SH 654 346], [SH 644 341]

Introduction

Set in dramatic mountain scenery in the remote and wild northern Rhinogs, the Llyn Du Bach Complex GCR site (Figure 5.5), comprising three small mines (Llyn Du Bach, Llyn Dywarchen and Llyn Eiddew-Mawr), serves to provide an excellent area in which to study the bedded manganese deposits occurring in the Lower Cambrian Hafotty Formation. The geological setting, stratigraphy and sedimen-tology of the manganese deposits are well illustrated; additionally it is possible to collect unweathered samples of the manganese ore for detailed mineralogical study. In addition, the methods of working the bed are well demonstrated at this site.

Manganese ores have been worked around the Harlech Dome since about 1835 (Down, 1980), although until the 1880s the scale of activity was small, merely working near-surface oxidized ore which was sent to Glasgow for use in the chemical industry (for the liberation of chlorine from hydrochloric acid in the manufacture of bleach). The 1880s saw an upsurge as a consequence of the discovery of the wear-resistant, enhanced hardness properties of manganese steels, which created a great demand for the metal. This evaporated, however, following the end of the First World War, although the mines that constitute this GCR site had closed long before, apparently only being prospected again in wartime. Total recorded production from these sites from 1889 to 1897 was 6158 tons (Down, 1980), the ore grade almost never exceeding 35% Mn and frequently dropping to 25%. These low grades were difficult to work profitably in such remote areas, and one major reason for the industry's demise was the increasing availability of higher-grade ores from overseas.

The manganese ores of the Harlech Dome have been examined in considerable detail (Woodland, 1939a; Mohr, 1964b; Glasby, 1974; Binstock, 1977; Bennett, 1987). Both Woodland (1939a), and Mohr (1964b) considered the manganese to be derived from an intensively weathered 'spilitic/keratophyric' terrain, the manganese precipitating as a colloidal gel containing rhodochrosite and silica in a climatically controlled evaporitic basinal environment. Subsequently, the model was modified by Glasby (1974), and later by Binstock (1977), who both inferred that the mineralization was an early diagenetic rhodochrosite precipitate and could have formed in a marine environment.

These models were questioned by Bennett (1987), however, who suggested that the weathered terrain model required unusual climatic conditions and basin-water chemistry, while the diagenetic model could not account for the quantity of manganese present, both in the ore-bed and in the overall sedimentary pile. He concluded that the mineralization was syngenetic/syndiagenetic, and was deposited from hydrothermal brines, the manganese precipitating out as manganiferous carbonates and oxides. Bennett (1987) suggested that the manganiferous brines could have been exhaled during submarine, basic to intermediate volcanism, and that a possible source area was either Anglesey or Llyn, where such volcanic rocks, of possible Cambrian age, existed. Bennett (1987) also commented that many original depositional features were preserved, despite mineralogical alteration at lower-greenschist-facies metamorphic grades.

Description

Manganese mineralization in the Harlech Dome comprises a discrete bed near to the base of the Hafotty Formation, which is a member of the Lower Cambrian Harlech Grits Group. The group consists primarily of medium- to coarse-grained, occasionally volcaniclastic, sandstones derived from proximal turbidites deposited in relatively shallow waters (Allen and Jackson, 1985). The Hafotty Formation is enriched in manganese (Bennett, 1987), but one horizon, the 'manganese ore-bed', approximately 0.5 m thick, contains up to 35% Mn. This ore-bed is remarkably persistent across the Harlech Dome, although it is thickest (approaching 1 m) in the south-west and thins to sub-economic levels in the east (Allen and Jackson, 1985) and it represents a notable marker horizon.

At the Llyn Du Bach Complex GCR site (Figure 5.6), the ore-bed has been worked opencast, the bed being removed and the waste being contained in pack-walled areas, between which tramways may be seen, along which the ore was conveyed from the working face. This method of working, common to many of the Harlech Dome manganese mines, is particularly well-displayed at the Llyn Eiddew-Mawr mine.

The ore-bed is a hard, dense, and splintery rock, cherry in appearance, with reddish and yellowish bands indicating mineralogical variation. Immediately below the ore-bed, in sharp contact, is a mudstone unit enriched in iron and containing magnetite and abundant pyrite. The upper contact of the ore-bed is gradational, and is overlain by a thick sandstone. This is well exposed on the miner's track from Llyn Eiddew-Mawr to Llyn Du Bach, as the track has been purposely excavated along the ore-bed in order to prospect it *en route;* along this track the overlying sandstones overhang spectacularly. At one point a fault crosses the bed, down-throwing it a small distance to the north-west; the track accordingly steps-up to follow the bed.

The best exposure of the ore-bed itself is situated at the end of this track, just beyond the Llyn Du Bach tarn, where a pile of ore has been blasted out but abandoned. In hand specimen, the alternating yellowish, pinkish-red, and reddish-brown banded nature of the finely laminated ore is readily seen.

The manganese ore-bed shows a number of original sedimentary features, including relict lamination, graded bedding, and flattened spheroidal microfossils (Bennett, 1987). Interbedded clastic units are also present, and a possible tuffaceous origin has been suggested by Bennett (1987), as they are widespread throughout the outcrop of the ore-bed and contain pseudomorphs after feldspar and vitric fragments. Carbonate microspherulites also occur in the ore, forming discrete layers; they are radially zoned with regard to their Fe and Mn content, zonation manifesting itself as concentric bands. The fact that at times one band is seen forming a zone around two touching micro-spherules indicates that they are in 'growth position'. Bennett (1987) commented that these small carbonate concretions are identical in many respects to those formed during the diagenesis of manganese-rich sediments in modern lacustrine and marine environments.

The yellowish bands, which contain more Mn than Fe, are composed mainly of micro-concretionary micritic calcian rhodochrosite but also contain pseudomorphs after probable authigenic gypsum or anhydrite. The red bands, which contain more Fe and less Mn, are composed of kutnohorite, spessartine, silica, hematite, magnetite and ferropyrophanite. Apatite, barite, rhodonite and pennantite have also been recorded (Bennett, 1987), while pyrite occurs as scattered 1–2 mm cubes, and irregular quartz veinlets are common. Interbedded thin clastic horizons have been altered by low-grade metamorphism into quartz-spessartine rocks, known as 'coticules', which also occur at several horizons within the Harlech Grits Group.

The limited extent of oxidation of the manganese ore at this site results in only thin films of grey manganese ores coating the primary ore, in contrast to many of the Harlech Dome manganese mines, where typically it has been oxidized extensively, with a deep-brown to greyish colour.

Interpretation

The diagenetic models of earlier authors to explain the origin of the Harlech manganese ore-bed were questioned by Bennett (1987) on a number of grounds. Firstly, the fact that manganese is enriched in the Harlech Grits Group relative to iron led Bennett (1987) to suggest that much iron must have been removed from the metallogenic system at source, rather than by localized, in-situ, diagenetic chemical fractionation. Such fractionation should theoretically lead to a relative depletion of manganese below the horizon of manganese mineralization, which is not the case in the Harlech deposit.

Secondly, Bennett (1987) noted the consistent positive correlation between manganese enrichment and the deposition of mud-facies sediments. This suggests that there existed an inverse relationship between manganese enrichment and sedimentation rates, such that, in general, manganese grades were diluted by clastic sediment input.

Finally, Bennett (1987) considered that the presence of volcaniclastic debris had a direct control on the precipitation of manganese from solution: specifically, early diagenetic alteration of volcanic debris in the presence of a Mn^{2+} flux would result in the formation of manganiferous smectites, which would then, under regional metamorphic conditions, evolve into spessartine-rich assemblages. An alternative was that thin limestone beds had reacted, either during early diagenesis or directly with the manganese-rich fluids, so that calcite was replaced by rhodochrosite. Such volcaniclastic and carbonate pre-ore protoliths have also been proposed as precursors to coticule formation in both the Venn-Stavelot Massif in Belgium (Kramm, 1976; Lamens *et al.,* 1986), and in southern Ireland (Doyle, 1984).

The above factors point towards a metamorphically evolved ore deposit which formed due to the reaction of manganese-rich fluids with seabed sediments, with a relatively low rate of sediment input permitting the accumulation of a relatively thick ore-bed. This was taken by Bennett (1987) to indicate that the ore-bed represents the distal component of a submarine sedimentary-exhalative hydrothermal system, drawing analogy with the modern metalliferous muds on the floor of the Red Sea.

In the model proposed by Bennett (1987), hydrothermal brines mixing with seawater would, due to the consequent decrease in temperature and salinity and increase in Eh and pH, release their contained metals as oxide precipitates in their order of solubility: thus, Pb, Cu, Zn and Fe would be early precipitates, dose to source, while the more soluble manganese would precipitate only when the less-soluble components had become sufficiently depleted. Bennett (1987) considered that the pyrite-rich pelitic bed Immediately below the ore-bed, with its slightly enhanced base-metal content, represented this initial stage of precipitation, followed by the deposition of manganese compounds to form the ore-bed itself. Rapid diagenetic alteration of manganese oxide precipitates to carbonates was cited in this model to explain the low Co-Ni-Cu content of the manganese ore, as the latter elements are generally highly enriched in seafloor manganese oxide nodules, the oxide being a strong scavenger of base-metal cations.

This hypothesis requires a source area in which sedimentary exhalative activity was taking place in early Cambrian times. Bennett (1987) cited the Mona Complex of Llyn and Anglesey as a possible source area, with its suite of basaltic lavas, cherts, jaspers and manganiferous sediments. However, this was based on a Lower-Mid-Cambrian age for parts of the Mona Complex (Barber and Max, 1979), and such an age has since been refuted subsequently by many authors (see Anderton *et al.,* 1992). Additionally, a source area to the north is perhaps incompatible with the distribution of the manganese ore-bed, which is thickest in the south-western part of the Harlech Dome, near Barmouth (Allen and Jackson, 1985), suggesting that the source area may have been located to the south-west of the Harlech Dome, where, unfortunately, the offshore Cambrian succession is buried under a considerable thickness of Mesozoic and Tertiary sediments (Allen and Jackson, 1985).

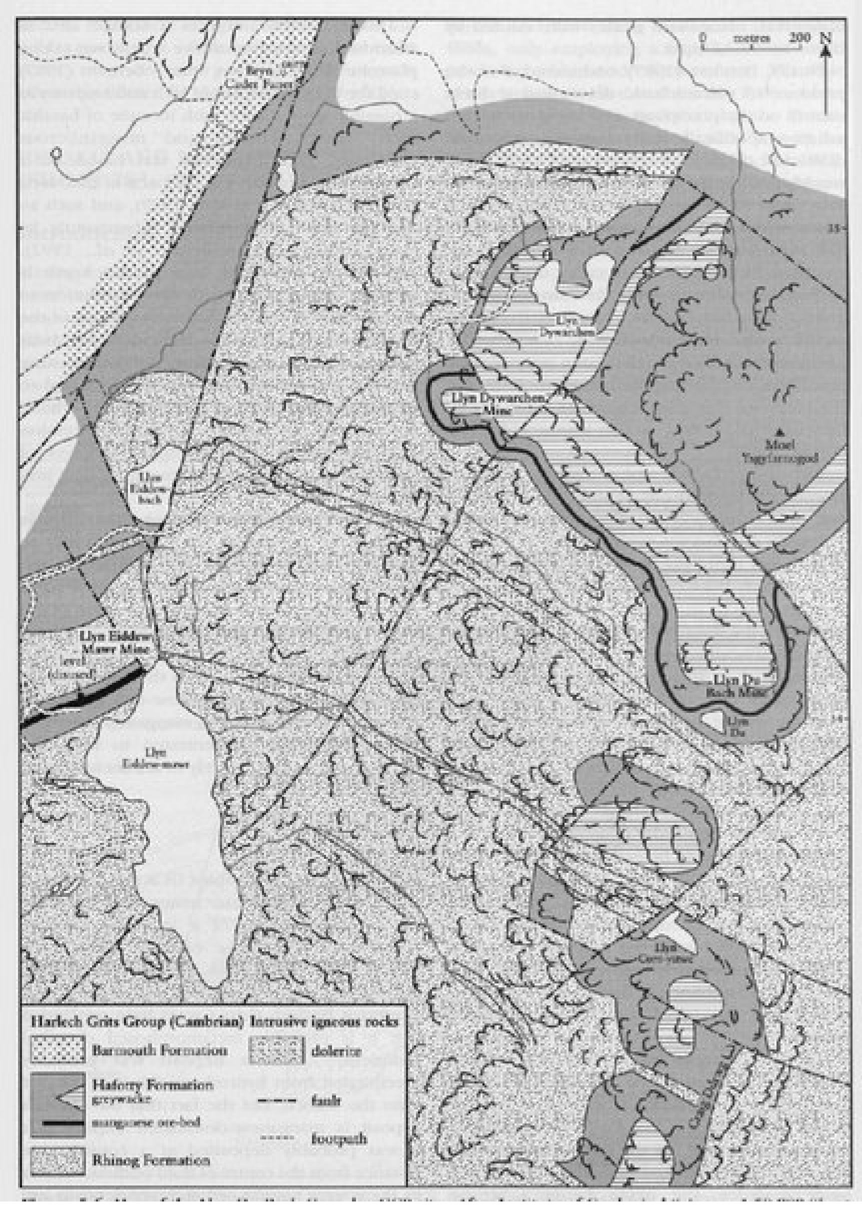
The fact that the entire Harlech Grits Group is enriched in manganese led Bennett (1987) to conclude that manganese was supplied to the depositional environment over a protracted period of time, but during the deposition of the lower part of the Hafotty Formation a brief reduction in the rate of clastic sedimentation occurred, leading not only to the deposition of muds, but also to the manganese-rich sediments. Therefore, the existence of manganese mineralization sufficiently concentrated to form the ore-bed may be due entirely to sedimentological factors.

Conclusions

The Llyn Du Bach Complex GCR site comprises three small manganese mines that illustrate the former working of a laterally extensive stratabound manganese ore-bed. The most recent detailed studies of this remarkably persistent manganese ore-bed within the Lower Cambrian Harlech Grits Group have concluded that it is probably metamorphosed chemical sediment. Such a deposit was probably precipitated from hydrothermal brines exhaled onto the seabed, but the fact that the Harlech deposit is manganese-dominated implies that it was probably deposited at a considerable distance from the centre of fluid outflow. Closer to the source similar sedimentary deposits are likely to occur which are enriched in Pb, Cu, Zn and Fe. Manganese ores, in economic terms, are only concentrated where sediment input breaks occur; otherwise any potential enrichment is effectively diluted by elastic sediment input.

References

(Figure 5.5) Photograph of old spoil-heaps of banded manganese ore adjacent to Llyn Eiddew-Mawr, at the Llyn Du Bach Complex GCR site, in the Harlech Dome region. (Photo: R.E. Bevins.)



(Figure 5.6) Map of the Llyn Du Bach Complex GCR site. After Institute of Geological Sciences 1:50 000 Sheet 135, Harlech (1982).