GLENDALOUGH DISTRICT

Introduction

Small quartz vein-hosted Pb-Zn(-Cu-Ba) deposits along the margin of the Leinster Granite batholith were worked episodically from the late 18th century to the 1950s. Lead ore was the main product although limited amounts of copper and silver, from argentiferous galena, were also produced. Efforts to produce zinc, notably in the 1950s, failed, possibly for want of proper processing technology. Most of the deposits were small, producing some 10s of tonnes of ore, but 45,000 tonnes of Pb, 60% of the total Irish output, was produced in the Glendalough District between 1826 and 1900.

The Glendalough district comprises a number of mine sites in three broadly parallel valleys that run northwest-southeast through the Wicklow mountains (Fig. 1). The northernmost valley, **Glendasan** (right), is separated from the **Glendalough** valley (below) by Camaderry mountain. These two valleys host most of the mine sites in the district. The rivers that drain them, the Glendasan and Gleneálo rivers, come together at the old monastic site in Glendalough to form the Avonmore River. In the south, the **Glenmalure** valley was the site of earliest mining in the district in the late 18[th] century. For the purposes of the HMS-IRC project, the district has been sub-divided into a number of sites: **Luganure-Hawkrock**, **Ruplagh**, **Hero**, **Foxrock** and **St. Kevin's** in Glendasan, **Van Diemen's** and **Glendalough Valley** in Glendalough Valley and **Ballinafunshoge** and **Barravore-Ballinagoneen** in Glenmalure.

Geology and Mineralization

The mineralization occurs in quartz veins that follow the line of faults or previously emplaced pegmatite/aplite veins. Their strike direction varies but most are oriented at a high angle to the Leinster Granite margin (Fig. 1). The longest vein, the Luganure Lode, was worked over a length of almost 3.5 km but is typically less than 6 m in thickness. In most instances, brecciation preceded and followed the deposition of sulphides. The mineralized veins are largely confined to the granite but a few cross the granite/wallrock contact where particularly rich mineralization has been found. The mineralogy of the veins includes major galena (PbS) and sphalerite (ZnS), subordinate chalcopyrite ($CuFeS_2$) and pyrite (FeS_2) and minor amounts of haematite (Fe_2O_3), tetrahedrite ($(Cu,Fe,Ag,Zn)_{12}Sb_4S_{13}$), native silver (Ag), pyrargyrite (Ag_3SbS_3), proustite (Ag_3AsS_3), covellite (CuS), rammelsbergite ($NiAsS_2$), jamsonite ($Pb_4FeSb_6S_{14}$), cassiterite (SnO_2) and scheelite ($CaWO_4$). The gangue consists of quartz (SiO_2), barite ($BaSO_4$), calcite ($CaCO_3$) and fluorite (CaF_2).

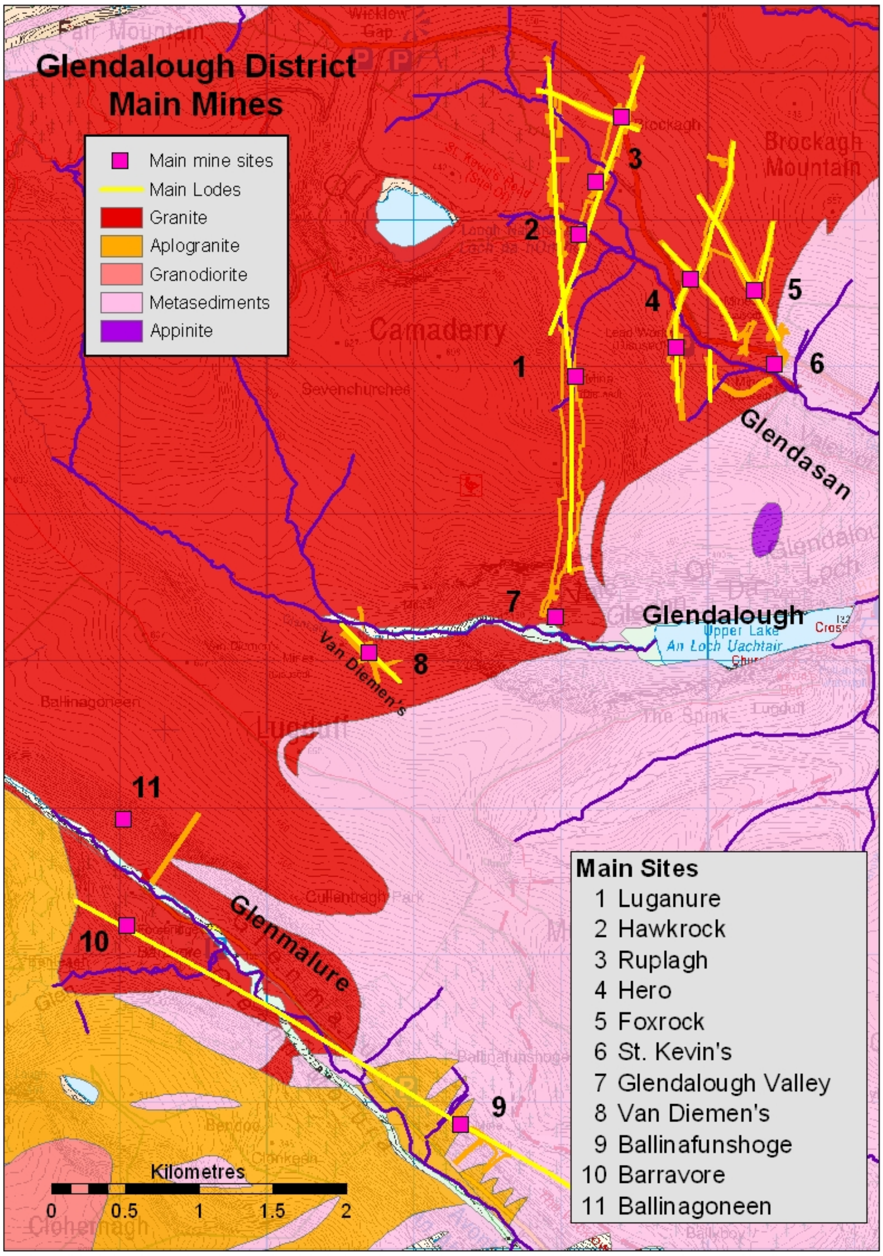

Fig. 1 Geology and mine sites of the Glendalough District

Mining History and Production

Lead mining began first in Glenmalure at the end of the 18th century but most of the production came from Glendasan where the first mining took place around 1812. However, large-scale development only occurred after the incorporation of the Mining Company of Ireland (MCI) in 1824. It acquired the lease in 1825 and mined almost continuously in the district until 1884. Its best period was from 1848 to 1870 when higher metal prices allowed more intensive development, yielding greatly increased tonnage and profits. In 1890 the Wynne family purchased the mine and made modest attempts at production over the following 40 years, notably involving processing of spoil in Glendalough Valley. In 1950 the Wicklow Mining Company was founded, partly on the basis of exploiting the zinc potential of the district. It carried out extensive deep development on the Moll Doyle and Foxrock lodes and built a new processing plant beside the Glendasan River (the St. Kevin's site, photo, right). It started mining in Glendasan in January 1952 and continued until the end of the decade.

The underground workings in the district are very extensive considering the narrow courses they were driven on. Maximum depth of workings below ground is approximately 400m though most levels are significantly shallower than this, with the median depth below ground about 80m. In all, over 40km of levels and shafts were driven, most of them in the 19th century. The mines were generally kept dry by drainage from the adits but deeper levels were pumped dry, using waterwheels powered by water from Lough Nahangan. Waterwheels were also used to raise ore. In 1871, a drought seriously reduced the amount of ore produced by MCI.

Most adits have now collapsed or are blocked off and the underground workings are in poor condition and inaccessible to the public (photo, right). There are extensive surface workings, including processing floors, spoil heaps, tailings ponds, the remains of mine buildings (offices, miners' accommodation, mill, dressing sheds, hoppers, etc.), wheel pits and the traces of plugged shaft openings.

Geochemistry

The geochemistry of mine waste in the Glendalough district is described separately in each site report. However, an overview of the chemistry of the district as a whole is presented here, with particular emphasis on stream sediments and surface water. Because each mine site in each of the three valleys can contribute to the chemical composition of stream sediments or river water samples in that valley, it is relevant to assess stream sediment and surface water chemistry in the context of the district as a whole. Stream sediments in the Glendasan River, for example, cannot in general be exclusively linked to any one mine site in Glendasan.

1. Surface Water

Surface water samples were collected in the district during winter (November 2006 – January 2007) and summer (July 2007). Winter adit discharge sampling was repeated at the beginning of March 2007 in order to measure flow rates. Samples included water from rivers and streams upstream and downstream of mine sites, adit discharges, seepages and run-off from waste heaps and ponded water on waste heaps. Details of the chemistry of water at specific sites can be found in the relevant site report. This section summarizes the water chemistry data for the district as a whole.

Owing to sustained heavy rainfall in July 2007 water levels in streams and rivers were similar to those that prevailed during the previous winter sampling campaign. Flow rates of adit discharges at the beginning of March 2007 were lower than those measured in July. Perhaps as a consequence of the relatively high flow rates in summer, there was no marked overall difference between the chemistry of winter and summer water samples from Glendalough. This is illustrated in Fig. 2 and Table 1 for Pb and Zn. Pb and Zn are the two elements of interest that are found in consistently elevated concentrations in water samples from Glendalough.

Surface drainage in the Glendalough district typically has somewhat low pH, reflecting its source in uplands that have extensive areas of blanket bog and coniferous plantations. Water draining from or running off the mine sites in the district typically has higher pH than water in streams and its acidity is low, normally well below 50 mg/l $CaCO_3$ equivalent. Thus, there is no AMD problem in the Glendalough district. If anything, mine waters may serve to ameliorate the slightly acid, nutrient-poor waters by raising the pH and by the addition of cations such as Na^+, K^+, Ca^{2+}, Mg^{2+} and Al^{3+}.

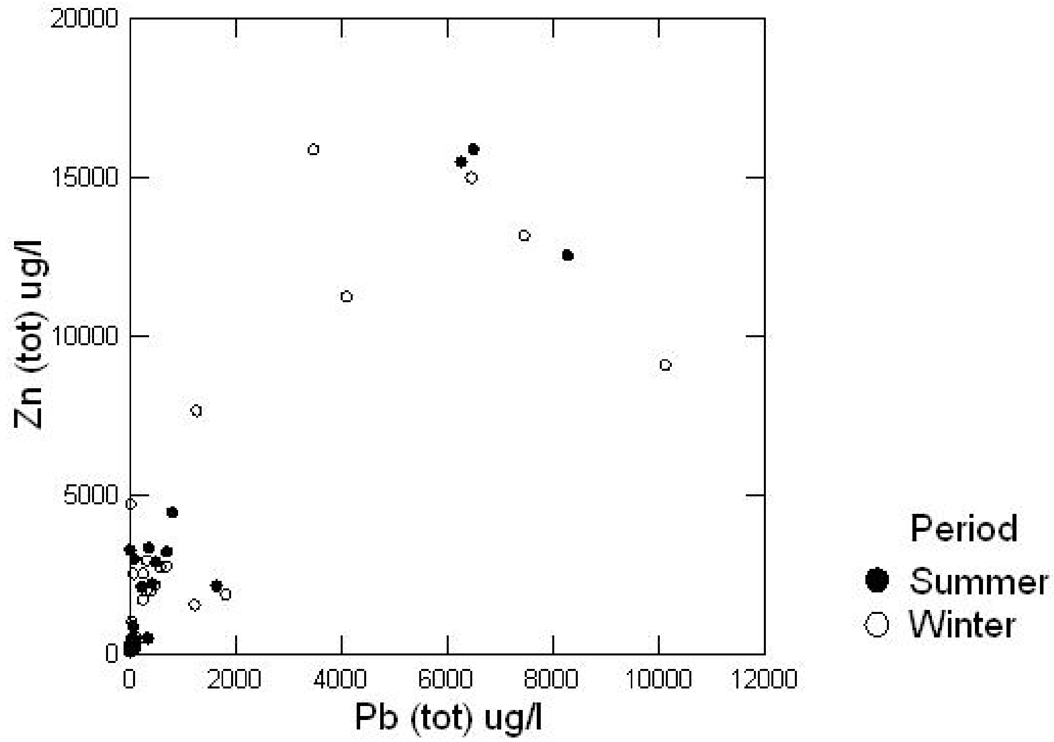

Fig. 2 Pb v Zn for summer and winter water samples, Glendalough district

Table 2 summarizes data for elements of interest in water collected from streams and rivers upstream and downstream of mine sites in summer 2006/7. The term “upstream” is not wholly accurate since a site upstream of one mine site may be downstream of another. Stream water that is contaminated by mine water at one site will recover to some extent as it undergoes dilution downstream and will be less contaminated when it reaches the next mine site. Thus, this categorization is still a useful one in Glendalough. As Table 1 shows there is a clear chemical distinction between “upstream” and “downstream” water samples. The latter have higher metal concentrations but also higher pH, reflecting the input of mine waters that generally have higher pH than the surface drainage in the Wicklow uplands. The median pH of mine waters (including adit discharges, run-off, seepage) for the same period was 6.2.

	pH	Acidity mg/l CaCO3	Pb (tot)	Zn (tot)	Cd (tot)	Cu (tot)
Downstream						
n	10	10	10	10	10	10
Minimum	4.9	7.6	4	73	<1	12
Maximum	6.9	78.0	133	371	2	58
Median	5.97	12.8	69	306	1	16.5
Upstream						
n	6	6	6	6	6	6
Minimum	4.6	8	4	90	<1	10
Maximum	6.1	96	105	292	<1	190
Median	5.6	11.8	7.5	91	<1	23.5

Table 1 Stream water, Glendalough, summer 2007

The distribution of metals in stream water in the Glendalough district is illustrated in Fig. 3. Summer Pb values are shown but the distribution is similar for Zn and for the winter period. Total Pb concentrations for samples collected in summer 2007 show significant variation across the district. Two trends are apparent on Fig. 3: (1) stream water in Glenmalure typically has lower Pb levels than that in Glendalough valley and Glendasan; (2) the highest concentrations of metals in stream waters occur in the lower Glendasan area. In Glenmalure, only the adit at Ballinafunshoge discharges mine water with significant concentrations of metals the Avonbeg River and the sample taken downstream of this site has relatively high Pb. Otherwise the Avonbeg River does not show a major impact from the mines. In Glendasan, several adits discharge into the Glendasan River downstream of the Hero processing area.

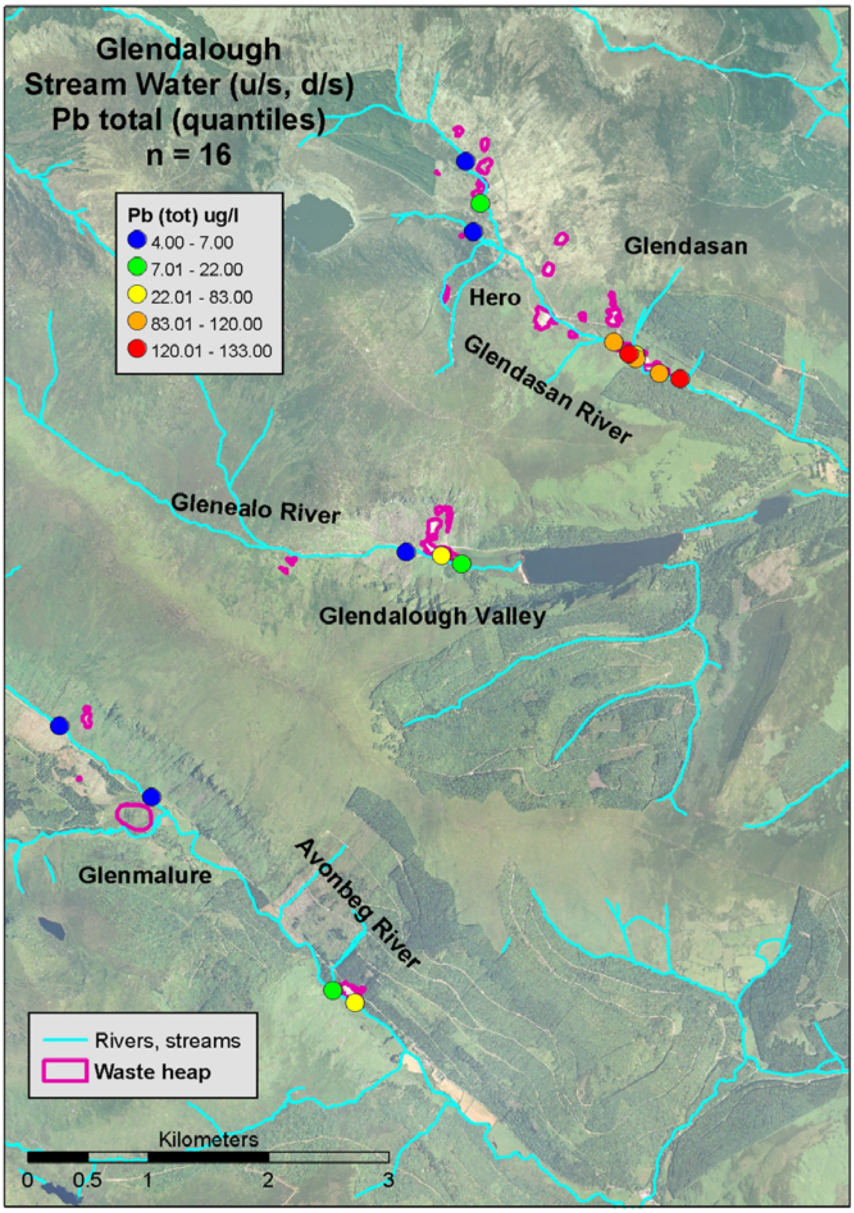

Fig. 3 Distribution of Pb in stream water, Glendalough (summer 2007)

Water samples can be broadly subdivided into two groups: (1) water from streams and rivers upstream and downstream of mines and (2) water that has been discharged from the mine through adits or shafts or has been in contact with mine waste (run-off and seepage). At Glendalough most water in the second category eventually flows into the local streams and rivers. Fig. 4 illustrates the range in Pb and Zn found in Glendalough waters and Table 2 breaks down the data by period, source and sample type (filtered or unfiltered/total). The overall similarity between filtered and unfiltered samples taken in summer and winter for each of the two main source types is striking. This implies that most Pb and Zn in these samples is in solution rather than in suspended particles.

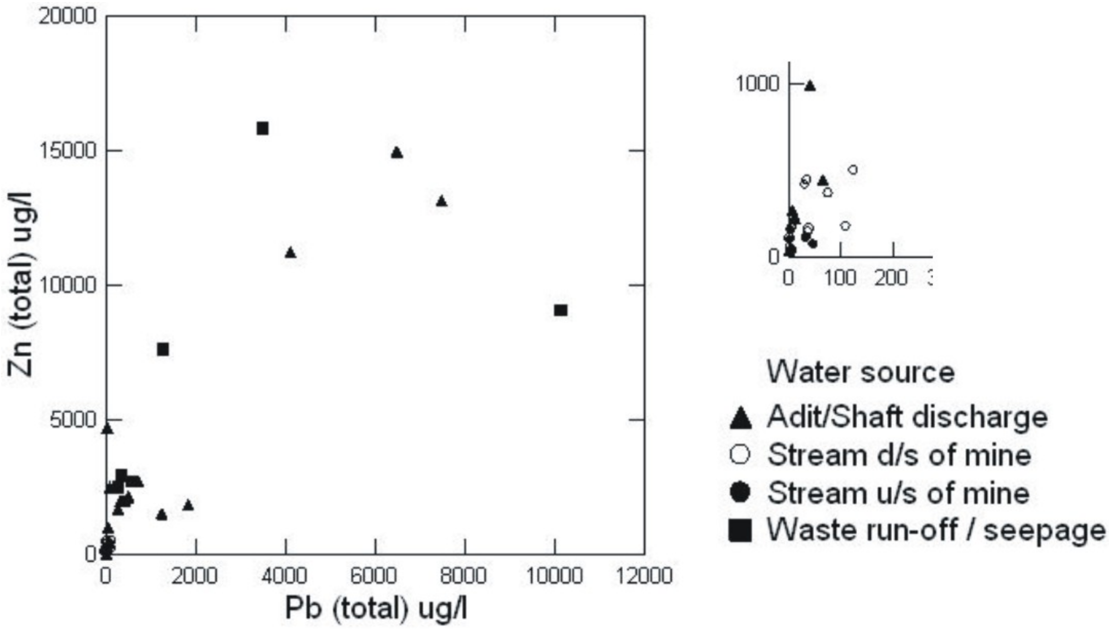

Fig. 4 Pb v Zn (total), all Glendalough District water samples (winter 2007). Inset: enlargement of area around origin to show stream water data.

		Stream water		Mine water	
		Winter	**Summer**	**Winter**	**Summer**
	n	***16***	***16***	***17***	***17***
Pb tot	***Range***	2 – 125	4 – 133	0.5 – 10140	3 – 8291
	χ	36	55	1750	1549
	Median	33	39	334	365
Pb diss	***Range***	0.5 - 120	0.5 – 132	0.5 – 8574	0.5 – 8637
	χ	28	53	1551	1610
	Median	15.5	37	269	339
Zn tot	***Range***	33 – 500	73 – 371	40 – 14960	71 – 15860
	χ	196	207	4005	4256
	Median	154.5	168	2500	2864
Zn diss	***Range***	20 – 522	13 – 336	30 – 17480	26 - 18890
	χ	169	156	4658	4878
	Median	125	102	2732	3217

Table 2 Summary statistics for Pb and Zn in water, Glendalough District

Mine water samples are enriched in Pb and Zn (Table 2) but the volume of such water is relatively low and the impact on stream and river water, though well defined (Fig. 3), is very modest in absolute terms. At lower Glendasan, where the greatest impact is observed, the measured volume of water discharged from the various adits in summer ranged from <1 l/s to 6.4 l/s, totalling around 10 l/s. Concentration of Pb (tot) in these adit discharges ranged from 238 to 1649 µg/l. The maximum Pb recorded in the river, at the site furthest downstream (Fig. 3), was 133 µg/l.

2. Groundwater

Groundwater was not sampled for the HMS-IRC project. Leachate analyses were carried out on solid waste samples from various mine sites in order to define the potential for waste heaps to contaminate groundwater in their vicinity. The results of these analyses are described in each site report.

3. Stream Sediments

Stream sediment samples were taken at 24 sites upstream and downstream of the various mine sites in the district. Most samples were of the <150 µm or <125µm fraction but six were <2mm fractions, a reflection of the immature drainage system in this upland area where fine-grained sediment constitutes only a small fraction of the total. A number of samples were also collected in the district during GSI's Regional Geochemistry programme in 1986. The sites for these are plotted on Fig. 5 which shows the distribution for Pb in samples collected for the HMS-IRC project.

Table 3 summarizes the data for elements of interest in stream sediments in the Glendalough district. Also included are median values for two subsets of GSI's Regional Geochemistry programme (1986-1990) data (unpublished data, GSI): one is for the additional sites in the Glendalough area (n = 18) as shown on Fig. 5, the other is for all stream sediment samples from sites overlying the Leinster Granite (n = 452). The latter is included because, although the additional sites in the Glendalough area are in streams draining the Leinster Granite, most overlie the sedimentary rocks to the east. Concentrations of Pb, especially, tend to be higher in granitic rocks and the regional data for the Leinster Granite are therefore another useful comparator for the HMS-IRC data.

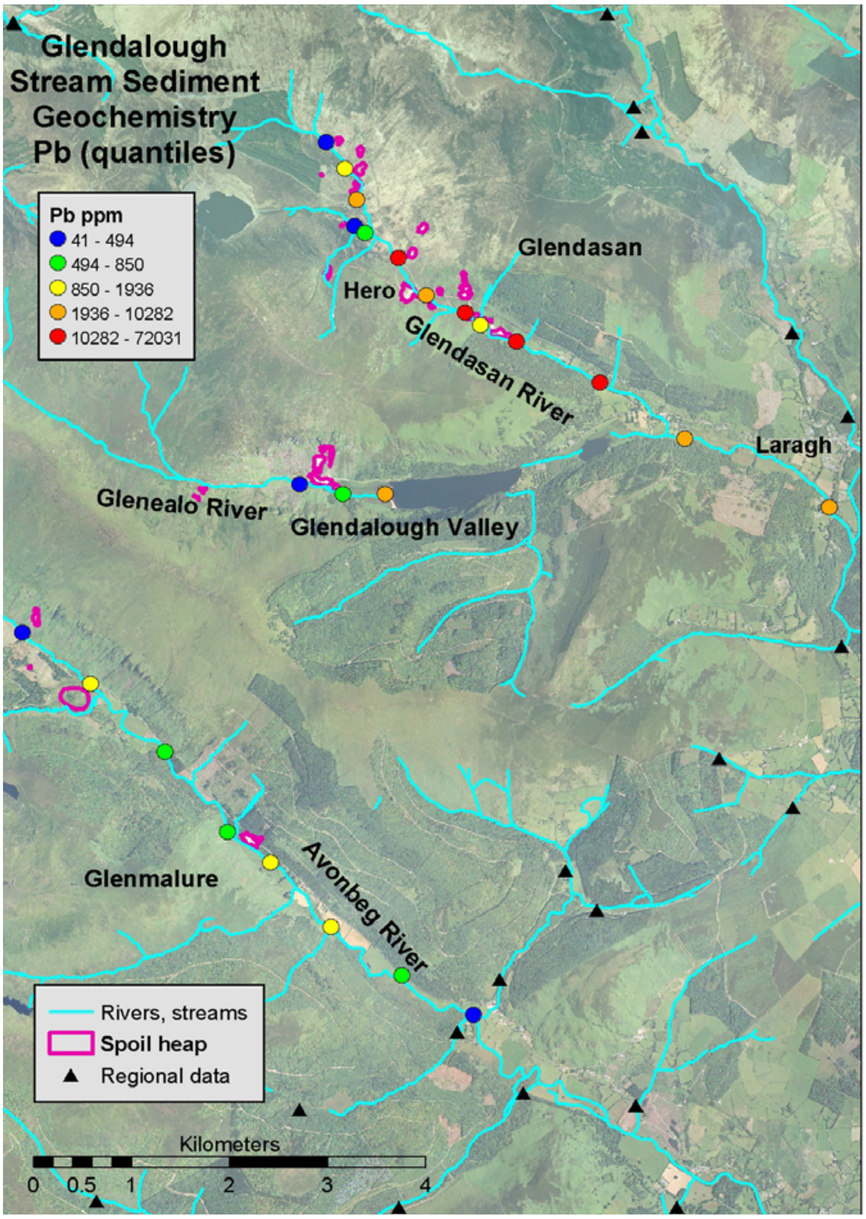

Fig. 5 Stream sediment Pb, Glendalough district

mg/kg	Pb	Zn	Cu
n	24	24	24
Minimum	41	48	0.0
Maximum	72031	68915	911
Median	1130	1490	39
Mean	7557	8841	165
Median (Glendalough area, GSI)	44	119	21
Median (Leinster Granite, GSI)	61	92	19

Table 3 Data for stream sediments, Glendalough District (HMS-IRC)

Table 3 demonstrates that Pb and Zn are significantly enriched in stream sediments in streams draining the mine sites in the district. This enrichment persists for considerable distances downstream of the mines. The sample site furthest downstream of Glendasan and Glendalough Valley mines, some 4km from the closest mine site (Fig. 5), had 7215 mg/kg Pb and 2930 mg/kg Zn. At Glenmalure, the sample furthest downstream, c. 3 km below Ballinafunshoge mine, had 494 mg/kg Pb and 193 mg/kg Zn. The maximum concentration for Pb (7.2%) was recorded immediately downstream of St. Kevin's mine, the last mine site on the Glendasan River (Fig. 1, 5). The six samples taken on the Glendasan River from Hero mine to a point 1 km below the tailings area at St. Kevin's mine, which include all the points in the highest quantile on Fig. 5, had median values of 1.5% Pb and 2.6% Zn. Sediments in the Glendasan River are clearly more affected by mining than any others in the district, in particular those in the stretch below the Hero processing area. Apart from the number of sites in Glendasan, the operation of two processing areas, at Hero and St. Kevin's, would be expected to lead to significant downstream contamination of the river.

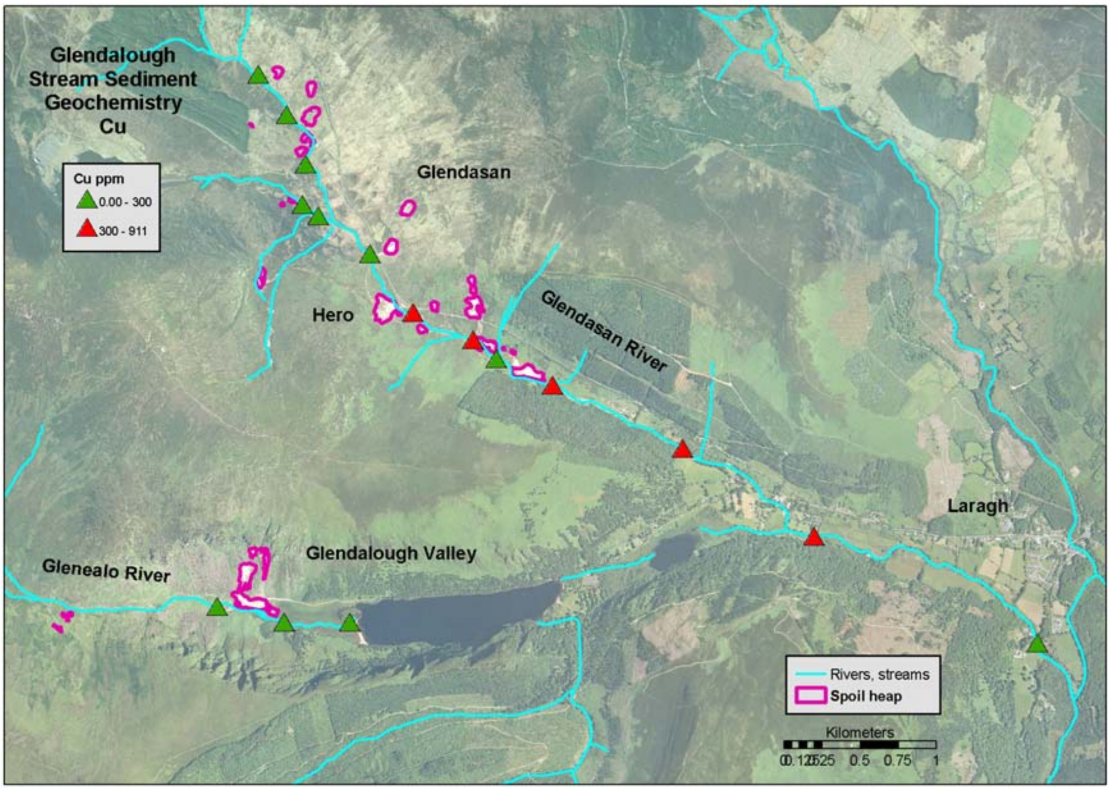

Fig. 6 Cu in stream sediments, Glendalough district (part)

Other elements of interest show only limited if any enrichment. Cu is not a major component of the ore in the Glendalough district but it has been described from most veins in Glendasan, particularly Hollyrock, Hero and Foxrock (Fig. 1) (Williams 1984). Samples analysed at the Hero processing area are relatively enriched in Cu (median Cu in processing area = 517 mg/kg; median Cu in spoil heaps = 110 mg/kg) and all the highest Cu values in stream sediments the Glendalough district (top 20% quantile, i.e. > 300mg/kg) occur downstream of this site (Fig. 6).

4. Solid Waste

Solid waste was analysed *in situ* by portable XRF on most sites in the district. A total of 381 analyses were completed in the field. Table 4 provides a statistical summary of the data for the district. Fig. 6 shows the distribution of Pb in the district, with Glenmalure inset. Very high concentrations of Pb and Zn were recorded at a number of sites, chiefly the processing areas at Hero in Glendasan and Ballinafunshoge in Glenmalure. A small processing area in Glendalough Valley also has high Pb concentrations as does some of the tailings deposit at St. Kevin's mine site in Lower Glendasan.

Table 4 Statistical summary, solid waste analyses, Glendalough District

mg/kg	Pb	Zn	Cu	Cd	S
n	381	381	381	381	381
Minimum	99	64	0.0	0.0	0.0
Maximum	194677	192785	3993	660	32316
Median	7912	4891	165	51	0.0
Mean	22440	8783	336	63	4013

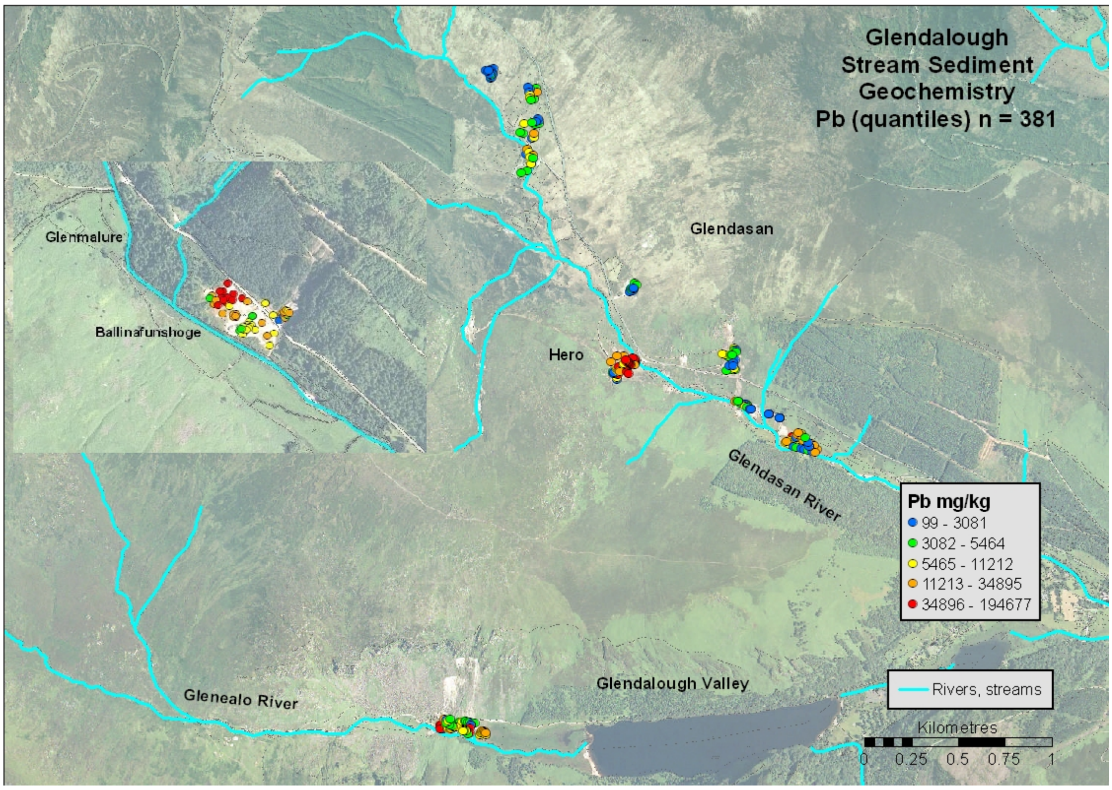

Fig. 7 Solid waste XRF analyses, Glendalough District: Pb

5. HMS-IRC Site Score

The total HMS-IRC site score for the Glendalough District is 1457 (Table 5). Fig. 8 shows the breakdown of this score according to waste source. Solid waste accounts for almost 50% of the total score while mine discharges, chiefly those in Glenmalure and Glendasan, account for 28.8%. The high proportion of the score accounted for by solid waste is to be expected given the presence of several processing areas with very high Pb concentrations and the large aggregate volume of waste. The total score for the discharges is 419 and the Ballinafunshoge adit discharge (239) accounts for almost 60% of this, a reflection of the extremely high Pb concentrations measured in it. The bulk of the stream sediment score (369) is made up of the Glendasan (189) and Glendalough Valley (156) stream sediment scores. Most of the very high concentrations of Pb found in stream sediment were in the Glendasan River, downstream of the Hero site (Fig. 5).

Table 5 HMS-IRC Site Scores, Glendalough District

Waste	Solid Waste	Discharges	Stream Sediments	Totals
1. Hazard Score	2037	2244	1458	5739
2. Pathway Score				
Groundwater	136.41	124.91		261.32
Surface Water	409.58	294.87		704.44
Air	15.93			15.93
Direct Contact	106.13			106.13
Direct Contact (livestock)			369.62	369.62
3. Site Score	**669**	**419**	**369**	**1457**

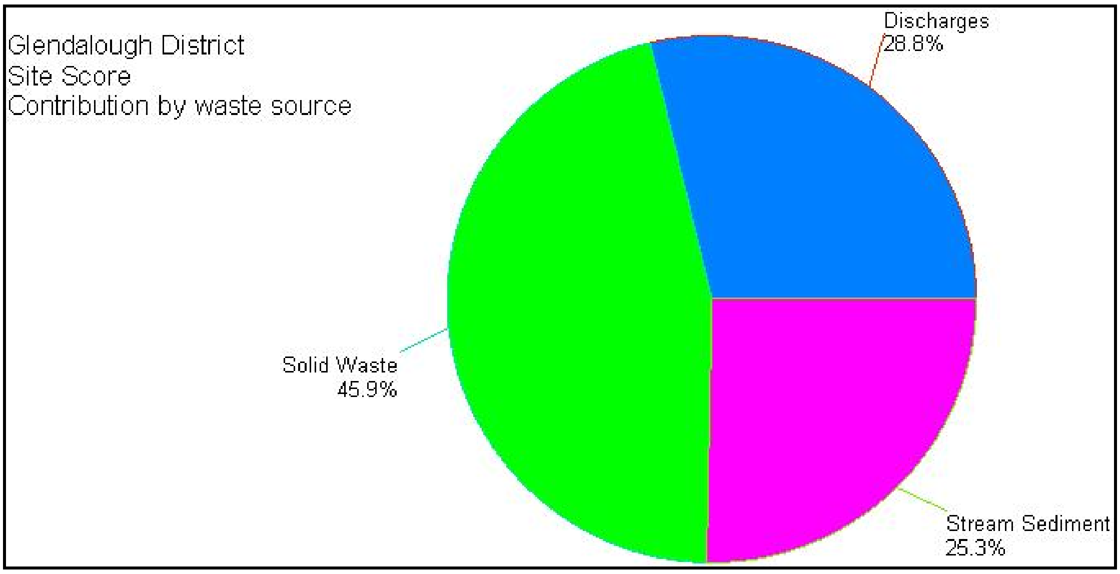

Fig. 8 HMS-IRC Site Score, Glendalough District: contribution by waste source

Fig. 9 shows the breakdown of the Glendalough District site score by pathway. As is the case for individual sites in the district, the surface water pathway (48.3%) dominates the scores. This reflects both the proximity of the sites to surface water receptors, i.e. the three rivers, but also the low density of housing in the area which minimizes the groundwater pathway because there are few wells that can potentially become contaminated. The Direct Contact (livestock) pathway score of 370 (25.4%) is a large absolute score for stream sediments, exceeded in Ireland only by that for Silvermines. It would be significantly higher, in excess of 400, if there direct evidence for livestock accessing streams. The Direct Contact pathway score (106 or 7.3%) is made up chiefly of contributions from three sites: Hero processing site, St. Kevin's tailings deposit and Ballinafunshoge processing site. The absolute score is relatively high and reflects the accessibility of the sites, their popularity with visitors and the high Pb concentrations in the waste.

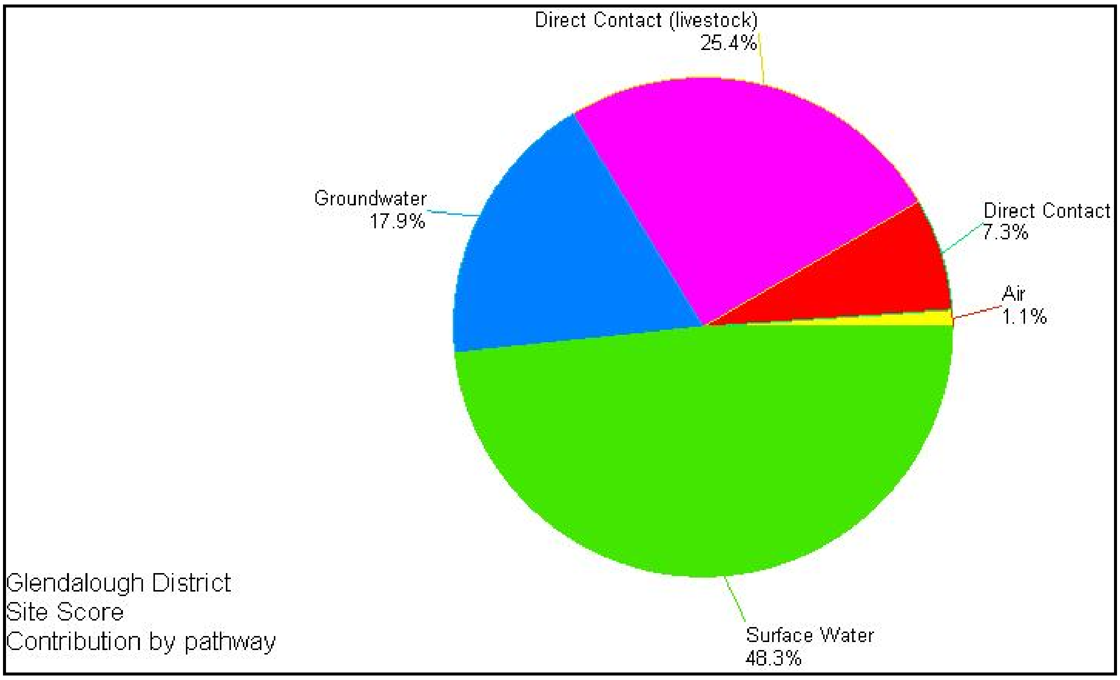

Fig. 9 HMS-IRC Site Score, Glendalough District: contribution by pathway

In considering the total HMS-IRC Site Score for the Glendalough District, it is considered logical to treat the Glenmalure sites separately from the Glendasan and Glendalough valley sites. Whereas they are reasonably considered to comprise a district from a geological and metallogenic perspective, the Glenmalure sites are some distance from the Glendasan and Glendalough Valley sites and do not share any common ore veins. In contrast, the workings in Glendasan and Glendalough Valley exploited some of the same lodes and ore from Glendasan was processed in Glendalough Valley. Therefore, while the total HMS-IRC Site Score for the Glendalough District is 1457, the district has been split into two sub-groups for the purpose of national ranking of the sites: the Glendasan-Glendalough Valley group has a HMS-IRC Site Score of 1122 (Class II), while the Glenmalure sites have a total score of 335 (Class III).

6. Geochemical overview and conclusions

The Glendalough District has a very extensive history of 19th-century lead and silver mining that has left a striking physical legacy in the three valleys that comprise it: Glendasan, Glendalough and Glenmalure. In addition to numerous ruined mine buildings, white quartz-rich solid waste heaps are a feature of the district. All of these contain significant measured concentrations of Pb and Zn and some, notably those on old ore processing sites, have very high concentrations, with maximum recorded values of Pb of almost 20%. Several significant adit discharges drain to the Glendasan, Glenealo and Avonbeg Rivers. These discharges contain significant concentrations of contaminants, chiefly Pb and Zn, but including Cu and Cd, and have a measurable impact on the water quality in the rivers downstream of the mine sites, albeit over short distances. Stream sediments, in contrast, are contaminated over very extensive lengths of the rivers downstream of the mines. The worst affected is the Glendasan River, with concentrations of up to 7.2% Pb measured in stream sediments downstream of the mines. Contamination of stream sediments has been measured at least 4km downstream of the Glendasan sites. The total HMS-

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