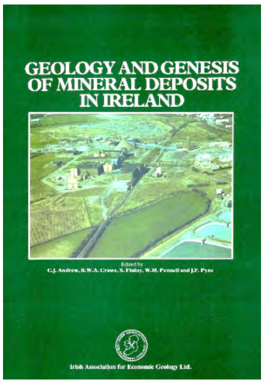

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W.G. O'Keeffe

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Age and postulated source rocks for mineralization in Central Ireland, as indicated by lead isotopes.

W. G. O'Keeffe

University College Dublin,
Belfield,
Dublin 4.

Abstract

Lead isotope ratios of galenas from a large number of deposits in Central Ireland reveal important temporal and genetic relations between Lower Palaeozoic- and Carboniferous-hosted deposits. Lead veins hosted in the Lower Palaeozoic rocks of the Longford-Down Inlier are of the same age and have been derived from the same lead sources as the surrounding Carboniferous-hosted deposits. Other Lower Palaeozoic-hosted deposits, e.g. Charlestown and Clontibret, reflect earlier mineralization episodes but have tapped the same lead sources as the later Carboniferous deposits. The lead isotope pattern reflects mixing between two isotopically distinct Pb sources. The less radiogenic source has a mantle lead signature while the more radiogenic source has crustal type characteristics. Data from deposits across Central Ireland define a simple regional pattern; the isotopic compositions become progressively more radiogenic towards the southeast. The trace of the Iapetus Suture cannot be recognized. Deposits to the north of Charlestown and hosted in Carboniferous and Dalradian rocks are, however, distinctly different in their isotopic composition, and reflect the involvement of a different crustal source.

Introduction

The results of a regional lead isotope investigation of mineralization in Central Ireland are presented. The study began by analysing galena from small lead veins hosted in the Lower Palaeozoic rocks of the Longford-Down Inlier (Fig. 1). As the study progressed and specific trends began to emerge, the surrounding Carboniferous-hosted deposits were analysed. Results for deposits hosted in the Dalradian rocks of Connemara and Donegal and for deposits hosted in the Lower Palaeozoic rocks of Charlestown and SE Ireland are also reviewed.

The purpose of this study is firstly to investigate possible source rocks for the lead mineralization, and secondly to investigate any temporal and genetic relations between individual deposits.

Analytical procedure and precision

The analyses were carried out at University College, Dublin, on a "V.G. Micromass 30" mass spectrometer. Purified lead was obtained using analytical grade AG 1-*8 anion exchange resin (200-400 mesh). Pb was eluted with 6M HCl and loaded on a single rhenium filament with phosphoric acid and silica gel. Samples were corrected for mass fractionation by normalizing the results to the NBS Pb standard (SRM 981). Repeat analyses of the standard indicate an overall reproducibility error of $< 0.1\%$ (2 standard deviations). Within-run precision is generally better than 0.04% (2 standard errors of the mean).

Lower Palaeozoic-hosted (Longford-Down) deposits

The isotopic composition of the epigenetic lead vein deposits hosted in the Lower Palaeozoic rocks of the Longford-Down Inlier (Table 1) are plotted on Figure 2. The bulk of the deposits lie below the conformable growth curve of Stacey and Kramers (1975) indicating a relatively unradiogenic source for the lead. However, as is typical of a related suite of anomalous leads, the data form a linear array on the lead-lead plot indicating a common time of mineralization. The results show a very simple regional pattern of variation. The sites at the northwestern part of the Inlier e.g. Red Hills, have the least radiogenic isotopic composition. The ratios gradually become more radiogenic towards the southeast. This regional pattern forms a framework for the rest of the study.

Carboniferous-hosted deposits

The isotopic composition of galena from the surrounding Carboniferous-hosted deposits (Table 2) is superimposed on the Longford-Down trend (Fig. 2). The pattern of variation in the Carboniferous cover rocks is identical. The isotopic composition of galena hosted in the basal Carboniferous rocks at Cloone, which lies just to the northwest of the Inlier, represents the least radiogenic Carboniferous-hosted deposit. Again the isotope ratios become more radiogenic towards the southeast. The isotopic composition, therefore, is a function of geographical position. All the analysed sites fall on the same linear array on the lead-lead plot. A common time of mineralization for the Lower Palaeozoic-hosted and Carboniferous-hosted deposits is implied.

Charlestown Inlier

The isotopic composition of galenas from the Charlestown Inlier (P. O'Connor, unpublished data) are plotted on Figure 3. The ratios, as might be expected from their geographical position, are less radiogenic than any from the Longford-Down Inlier. However, on Figure 3 it can be seen that the isotopic composition is distinctly offset from the established Longford-Down/Carboniferous array. The nature of this offset is such as to suggest a similar source for the lead at Charlestown and at Red Hills, but reflecting an earlier mineralization event. Assuming a lower Carboniferous age of mineralization for the least radiogenic Red Hills sample, a U^{238}/Pb^{204} (μ) value of 9.15 is calculated for the source of the lead at Red Hills. The μ values are calculated using the Stacey and Kramers (1975) model starting point at 3.7Ga. The Charlestown leads intersect this growth curve at 470Ma. This is in good agreement with other independent work on the Inlier (O'Connor and Poustie, this vol.) which has established an Ordovician age for the mineralization.

Lower Palaeozoic-hosted stibnite (Clontibret)

The Lower Palaeozoic rocks of the Longford-Down Inlier are also host to an earlier Sb-As vein assemblage (Morris et al., this vol.) To investigate any isotopic relations between the earlier Sb-As assemblage and the later galena veins, stibnite from the Clontibret deposit (Fig. 1) was analysed. The stibnite contains up to 7 000ppm Pb. It is therefore unlikely that its isotopic composition has changed since its formation by *in situ* radioactive decay. The results (Table 3) are compared with a best fit line through the Longford-Down/Carboniferous trend (Fig. 3). The isotopic composition of the stibnite is clearly temporally offset from the Carboniferous array. A similar source for the lead in the stibnite and for that in the later galena veins is indicated. The age of the Sb-As vein assemblage is in fact coeval with late Caledonian intrusives (J. H. M. Morris, pers. comm). This is in good agreement with the lead isotope data. The nature of the offset shown by the lead in the stibnite is similar to that shown by the lead mineralization at Charlestown (Fig. 3). The degree of offset is less marked for the stibnite, however, as would be expected for mineralization of late Caledonian age.

Dalradian-hosted deposits

The results for galena samples hosted in the Dalradian rocks of Connemara (N. Reynolds, unpublished data) are plotted on Figure 3. The ratios show a large degree of isotopic variation over a small geographical area. The least radiogenic samples, however, fall close to the unradiogenic growth curve ($\mu = 9.15$) calculated for the source of the lead at Red Hills and Charlestown. The unradiogenic Dalradian samples intersect this growth curve at 670Ma. The analysed samples from the Connemara Dalradian are hosted in middle to upper Argyll Group rocks (McArdle et al., this vol.) The calculated age of 670Ma is in approximate agreement with the commonly accepted isotopic age of the tillite bed at the base of the Argyll (Pringle, 1973; Harris and Pitcher, 1975). The rest of the analyses show a large degree of variation (Fig. 3). Some fall to the left of the Carboniferous trend, and one sample falls on the Carboniferous line (Fig. 3). The results may be interpreted as representing three stages of mineralization. The earliest stage of mineralization occurred at 670Ma, followed by a later Caledonian event at 470Ma (possibly associated with the emplacement of large granitic intrusives), and finally a Carboniferous event.

SE Ireland

The results for galena veins from the margins of the Leinster Granite and from the copper deposit at Avoca are given in Table 3, and are plotted on Figure 3. The data lie above the Stacey and Kramers growth curve indicating a relatively radiogenic source for the lead. The Avoca deposit is hosted in a belt of Upper Ordovician volcanic rocks, known as the Duncannon Group, which formed in a continental margin volcanic arc setting (Sheppard, 1980). Leads derived from a volcanic arc typically have isotopic compositions which lie on or near the conformable growth curve and yield meaningful model dates. The isotopic composition of the Avoca deposit lies just above the growth curve (Fig. 3) and yields a model date of 440Ma which is in good agreement with the stratigraphic age.

The isotopic composition of leads from the Caim deposit is less radiogenic than that from Avoca, indicating an earlier time of mineralization (assuming the same lead source). The Caim deposit is hosted in rocks of the Ribband Group which is Upper Cambrian-Lower Ordovician in age. The isotopic composition of the galena from veins on the margins of the Leinster Granite is more radiogenic than that from Avoca, but as a group are offset from a best fit line through the Carboniferous deposits. The veins in the Granite are considered to be Caledonian (Kennan et al., this vol.). The isotopic composition of galena in the veins is less radiogenic than that from Harberton Bridge or Newcastle, implying a similar source for the lead but removal from that source at an earlier time.

NW Ireland

Lead isotope ratios over a large area in central Ireland from Cloone to Hook Head fall on the same regression line; there is no evidence for any break in the data (Fig. 3). The data show a similar progressive pattern of variation on a 208/204 versus 206/204 plot (Fig. 4). However, results for galenas hosted in the Donegal Dalradian and the Carboniferous Abbeytown deposit are distinctly different (Fig. 4). The calculated Th/U for the leads at Abbeytown is 3.55, which is lower than the average calculated Th/U ratio for the deposits to the south (3.76). The source for the leads to the north of Charlestown, therefore, seems to be depleted in Th relative to the source of the leads to the south.

Discussion

The results for the galena deposits of the Longford-Down Inlier and the Carboniferous-hosted deposits form a linear array on the lead-lead plot (Fig. 2). The slope is either the result of a multistage growth history where the lead resided in two or more source regions, or is the result of mixing of lead from two or more source areas. In the simplest case of a multistage history i.e. a two-stage lead, a source rock age for the lead may be calculated if the age of mineralization is known. Assuming a Lower Carboniferous age of mineralization, a source rock age of 3.2Ga. is obtained. This is older than any postulated basement under central Ireland. Since the slope of the data does not yield realistic basement ages, the obvious alternative is that the slope represents the mixing of lead from two different sources. The less radiogenic source is reasonably well defined. This is the growth curve with the μ value of 9.15. The more radiogenic growth curve must have a μ value greater or equal to the μ value for Harberton Bridge i.e. $\geqslant 10.09$. A summary diagram of the relations between the individual deposits is shown in Figure 5. The Carboniferous line is a best fit line drawn through the results for both the Lower Palaeozoic-hosted Longford-Down lead vein deposits and the Carboniferous-hosted deposits. The earlier Caledonian trend is represented by analyses from the Lower Palaeozoic-hosted Charlestown deposit, deposits in the Connemara Dalradian and results for the stibnite at Clontibret. The Caledonian trend parallels the later

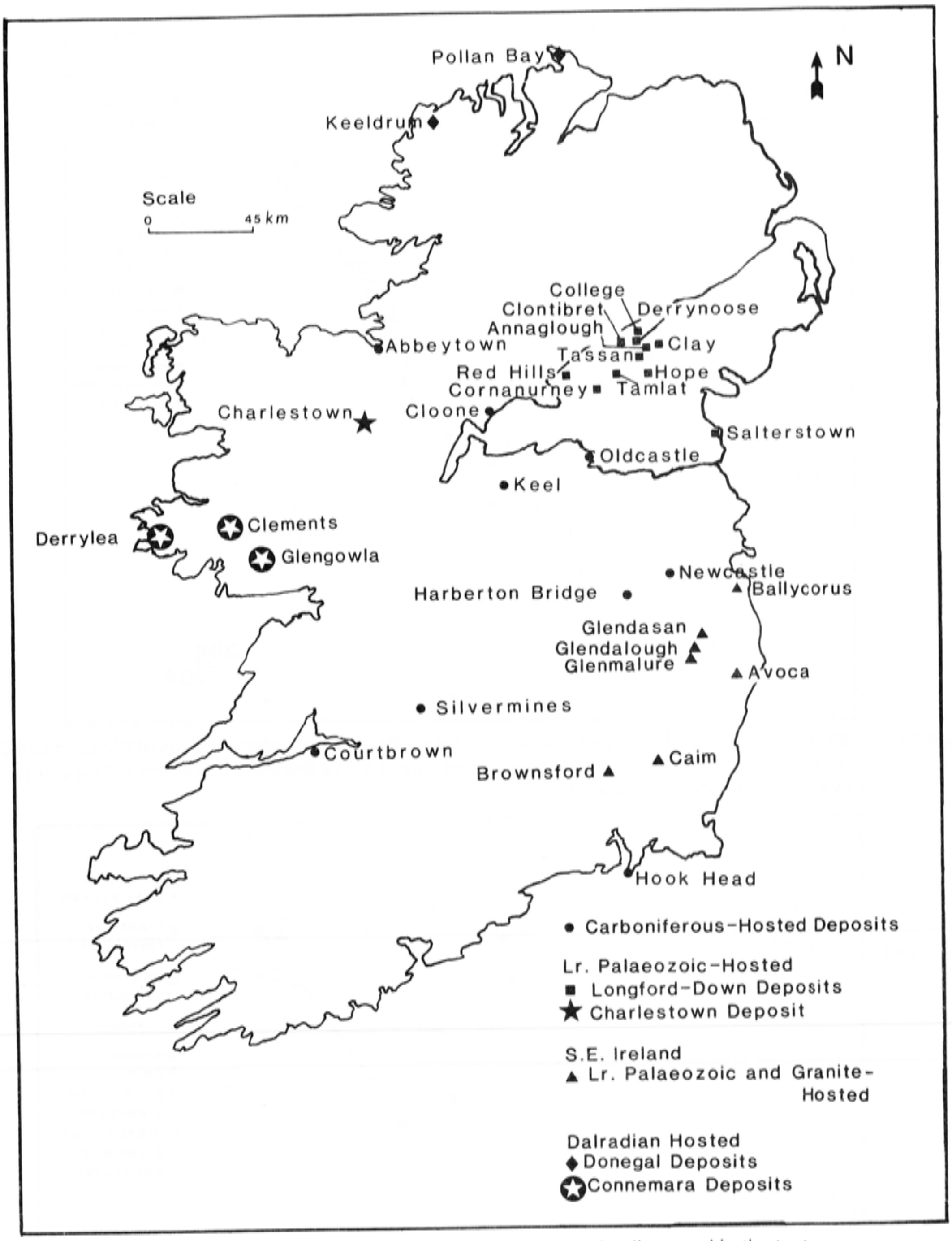

Figure 1. A map of Ireland showing the sites of mineral deposits discussed in the text.

Carboniferous line. This implies that the sources for the Carboniferous mineralization were already in existence during the Caledonian i.e. the isotopic composition of the stibnite requires a component of lead from both end members. As yet there is no evidence for the involvement of the more radiogenic end member during the early Dalradian.

The μ value of 9.15 is best typified by mantle-type environments. Estimates for depleted mantel at 60Ma (Dickin, 1980) and 400Ma (Frost and O'Nions, 1984) based on analyses for basalts from the Mid-Atlantic Ridge are also shown on Figure 5. These points lie along the same growth curve as that calculated for less radiogenic deposits. The less radiogenic end member therefore has isotopic characteristics which are best satisfied by a mantle type source. The leads in the northwestern part of the country (Red Hills, Cloone, Charlestown) have the most interaction with mantle-type lead with progressively less involvement to the southeast.

The Pb isotopic composition of galena mineralization hosted in the Dalradian rocks of Scotland have been interpreted as indicating the involvement of a mantle component in the ore genesis (Parnell and Swainbank, 1984). A mantle involvement is also proposed here as a source for mineralization hosted in the Dalradian rocks of Connemara. The close association between volcanic activity and mineraliza-

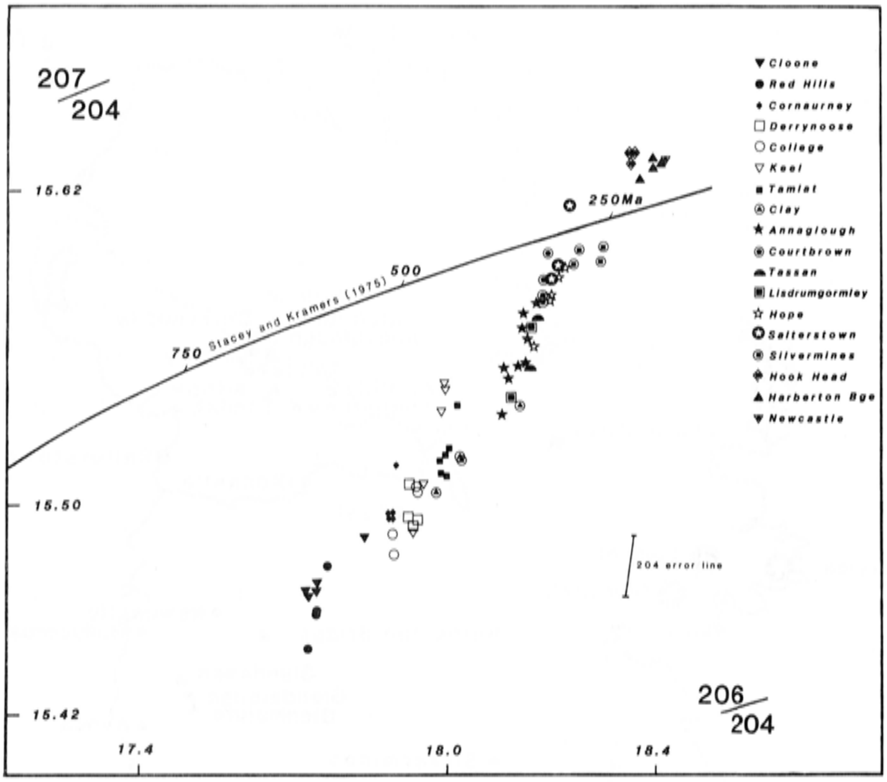

Figure 2. Lead isotopic composition of galenas from the Lower Palaeozoic-hosted deposits of the Longford-Down Inlier and the surrounding Carboniferous-hosted deposits. The Stacey and Kramers (1975) conformable growth curve is shown for comparison.

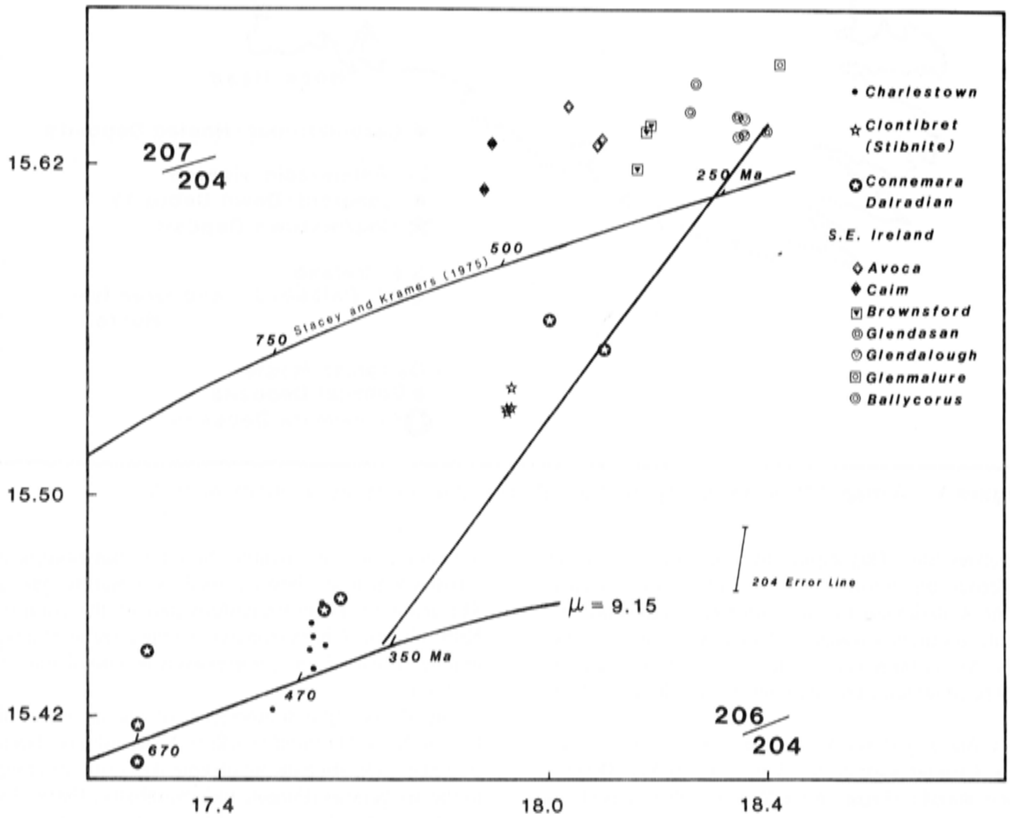

Figure 3. Lead isotope ratios for deposits from Charlestown, Clontibret, Connemara and SE Ireland compared with those from the Longford-Down Inlier. The growth curve for the unradiogenic source discussed in the text is shown.

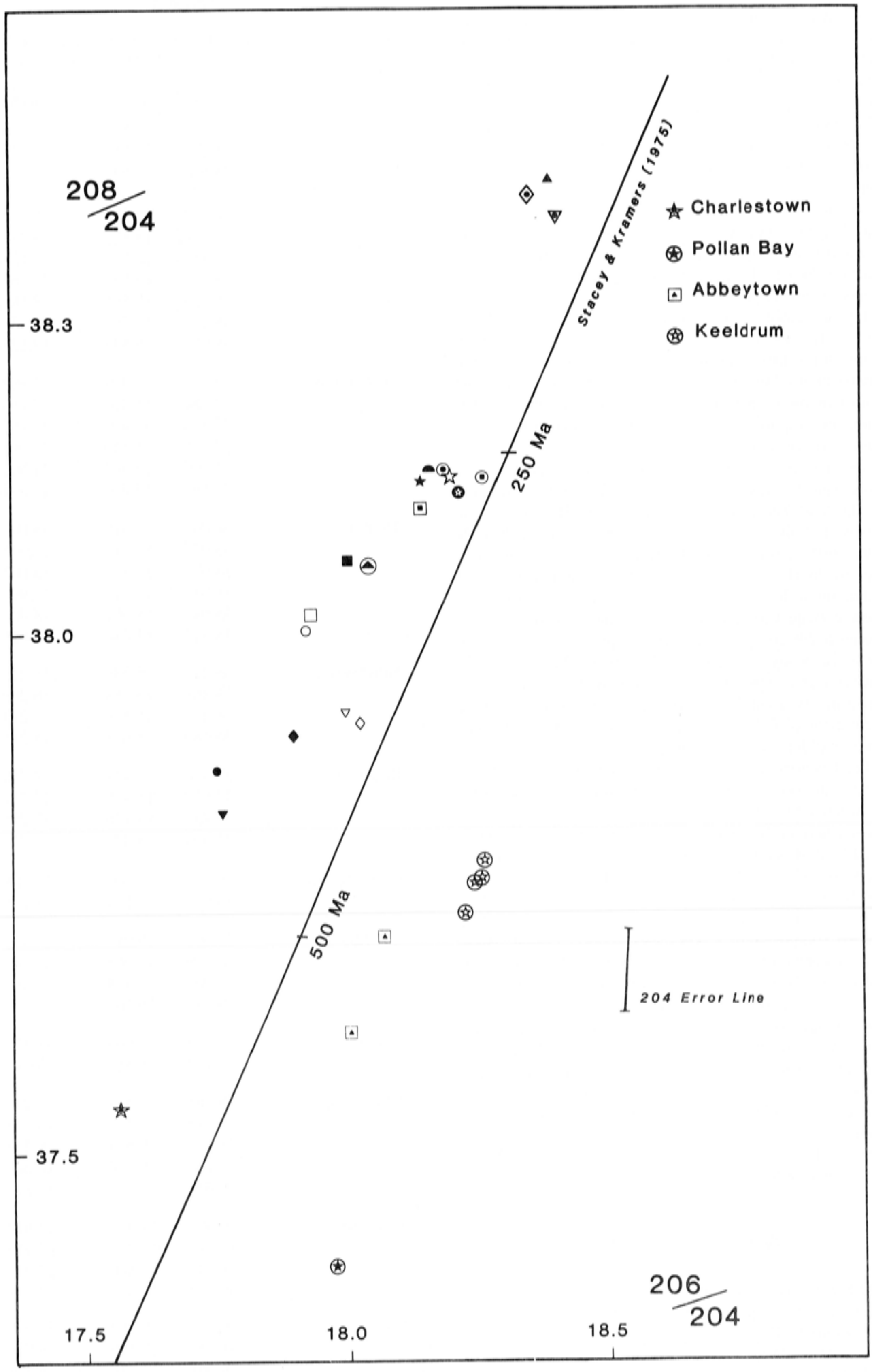

Figure 4. Lead isotope ratios for deposits hosted in the Dalradian rocks of Donegal (Keeldrum and Pollan Bay) and the Carboniferous-hosted Abbeytown deposit compared with the rest of the data. Each point represents an average for the deposit. Symbols as in Figure 2.

tion at Charlestown (O'Connor and Poustie, this vol.) is also consistent with a mantle involvement, as implied by the isotopic composition of the galenas from there. The stibnite from the Clontibret deposit is associated with igneous activity (Morris et al., this vol.). The Carboniferous-hosted deposits, however, are not temporally or spartially related to igneous activity, but it is possible that the ore fluids have interacted with, or have derived metals from, older magmatic rocks e.g. Lower Ordovician volcanics.

An alternative unradiogenic component could be an unradiogenic lower crustal or basement source. This is considered unlikely for the following reasons: a) the calculated μ value of 9.15 is best typified by mantle-type environments, b) the slope of the data on the lead-lead plot does not yield realistic basement ages, and c) the calculated Th/U ratios for the data are approximately 3.76, which is low for values normally associated with lower crustal environments. High grade metamorphism in the lower crust results in the preferential depletion of U relative to Th, often resulting in high (>4) Th/U ratios in the lower crust (Doe and Zartman, 1979).

The μ value of 10.09 for the more radiogenic source is more typical of upper crustal sources. The slope of the data on the lead-lead plot is extremely steep. Because of the relative half-lives of U^{238} and U^{235}, a large change in 206/204 ratios with respect to 207/204 ratios would be expected if the ore fluids had interacted with typical upper crustal sediments at the time of ore formation. The data, however, show a large variation in 207/204 values relative to the change in 206/204 values. This type of pattern would result if the more radiogenic contaminant were an older radiogenic crustal source. This radiogenic component may reflect the direct involvement of an older radiogenic crust or may be a component within the upper crustal sediments derived from an older radiogenic source.

Lead isotope data for mineralization of early Carboniferous and late Caledonian age form mixing line isochrons as defined by Andrew et al. (1984) on Figure 4. The involvement of the same two lead sources in the ore genesis during a number of mineralization episodes is indicated. A pre-Carboniferous source for the mineralization must be sought. Even though there is some within-site variation e.g. Keel, lines may be drawn through sites of similar isotopic composition e.g. Keel, Derrynoose, Tamlat. These have a northeasterly orientation and parallel the major Caledonian structures in Ireland (Boast et al., 1981; Caulfield et al., this vol.). It has been proposed that faults with this orientation, reactivated during Carboniferous times, have acted as feeding channels for mineralizing fluids (Morrisey et al., 1971). Such a model is consistent with the lead isotope data. Since the Lower Palaeozoic-hosted deposits of the Longford-Down Inlier are similar in isotopic composition to adjacent Carboniferous-hosted deposits, the implication is that the Carboniferous cover rocks have had very little effect on the isotopic composition.

Acknowledgements

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Table 1.

Isotopic composition of galena from the Lower Palaeozoic-hosted (Longford-Down) deposits.

	208/204	207/204	206/204
Annaglough	38.183	15.571	18.156
	38.122	15.551	18.143
	38.082	15.532	18.112
	38.121	15.550	18.117
	38.194	15.577	18.178
	38.108	15.552	18.155
	38.110	15.552	18.158(re)
	38.181	15.573	18.162
	38.153	15.561	18.161(re)
	38.177	15.565	18.151
	38.097	15.542	18.125(re)
Cornanurney	37.879	15.494	17.893
	37.886	15.495	17.899
	37.894	15.493	17.895
	37.928	15.513	17.908
	37.907	15.502	17.902
	37.893	15.493	17.894(re)
Tamlat	38.084	15.519	18.007
	38.027	15.515	17.992(re)
	38.072	15.517	18.002
	38.052	15.510	17.996
	38.040	15.509	18.003
	38.112	15.536	18.025
Salterstown	38.129	15.589	18.225
	38.109	15.584	18.209
	38.113	15.586	18.214
	38.189	15.613	18.241
Red Hills	37.830	15.443	17.738
	37.870	15.457	17.754
	37.862	15.456	17.751
	37.904	15.475	17.775
Lisdrumgormley	38.159	15.566	18.168
	38.080	15.539	18.128
College	37.997	15.487	17.900
	38.029	15.505	17.946
	37.964	15.479	17.904
	38.015	15.503	17.949
Tassan	38.183	15.569	18.179
	38.131	15.550	18.145
Hope	38.165	15.578	18.206
	38.116	15.558	18.173
	38.214	15.599	18.229
	38.165	15.580	18.202
	38.098	15.585	18.217
Derrynoose	38.005	15.490	17.940
	38.014	15.492	17.949(re)
	38.043	15.506	17.933
	38.004	15.493	17.933
Clay	38.029	15.503	17.986
	38.059	15.515	18.031
	38.063	15.516	18.029
	38.106	15.537	18.145

(re)=repeat analyses of previous sample.

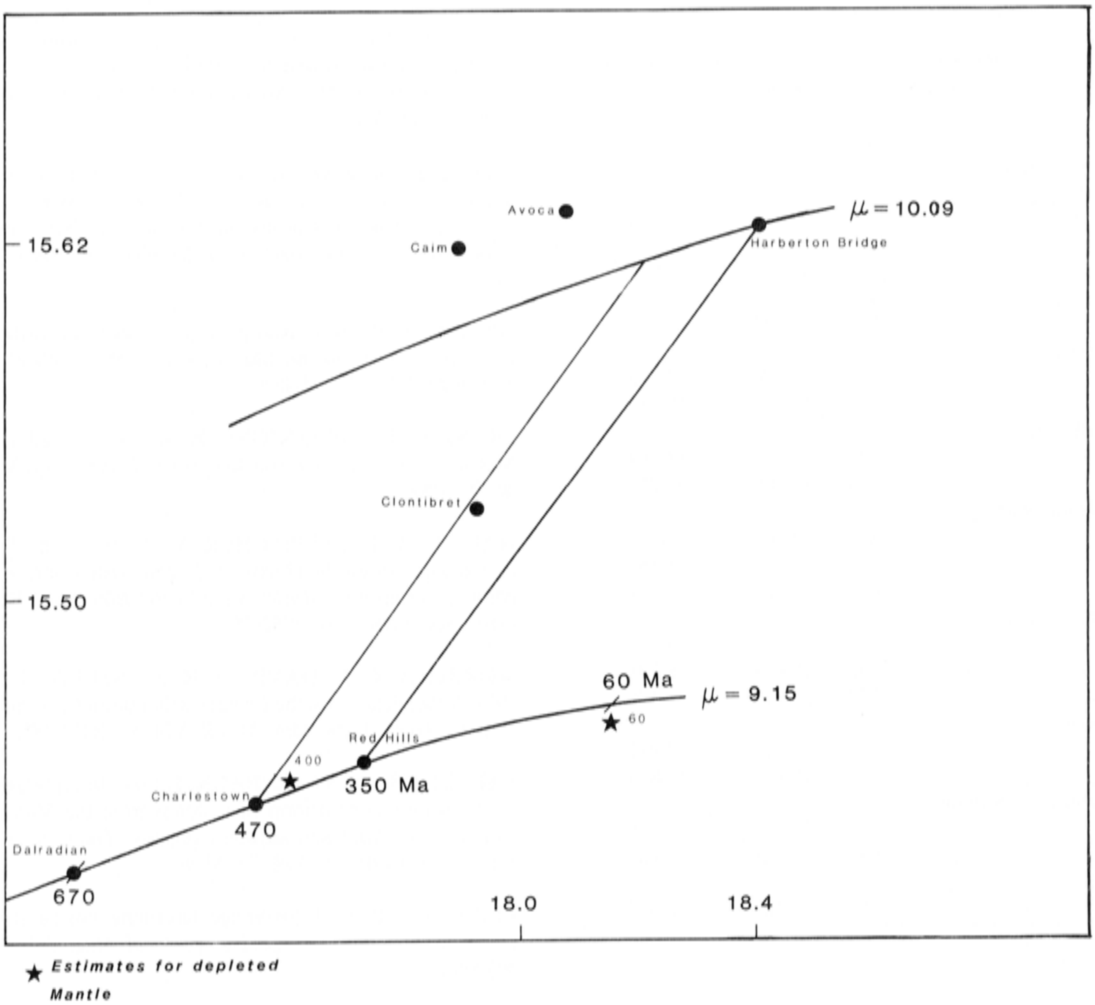

Figure 5. A summary model diagram of the relations between the individual deposits.

Table 2.

Isotopic composition of lead from Carboniferous-hosted deposits.

	208/204	207/204	206/204
Keel			
	37.936	15.546	17.996
	37.818	15.509	17.951
	37.943	15.548	17.994
	37.900	15.537	17.992
	37.764	15.490	17.932
Cloone			
	37.821	15.465	17.750
	37.820	15.465	17.751(re)
	37.896	15.486	17.844
	37.789	15.465	17.729
	37.797	15.463	17.736
	37.834	15.468	17.754
Harberton Bridge			
	38.445	15.627	18.402
	38.442	15.631	18.399
	38.404	15.623	18.376
	38.448	15.629	18.414
Silvermines			
	38.161	15.591	18.299
	38.181	15.597	18.305(re)
	38.131	15.590	18.246
	38.149	15.596	18.257
Courtbrown			
	38.135	15.578	18.188
	38.151	15.584	18.192
	38.190	15.590	18.200
	38.139	15.575	18.188
Abbeytown			
	37.615	15.496	18.016
	37.708	15.525	18.058
Hook Head			
	38.416	15.631	18.360
	38.426	15.631	18.357
	38.423	15.629	18.360(re)
Newcastle			
	38.398	15.618	18.413

Table 3.

Isotopic composition of leads from SE Ireland and stibnite from Clontibret.

	208/204	207/204	206/204
SE Leinster			
Glendasan			
	38.468	15.633	18.405
	38.407	15.638	18.350
Glenmalure			
	38.488	15.653	18.427
	38.142	15.627	18.107
Avoca			
	38.151	15.629	18.113
	38.131	15.641	18.053
Ballycorus			
	38.296	15.640	18.264
	38.334	15.650	18.276
Glendalough			
	38.419	15.631	18.357
	38.409	15.632	18.361
	38.411	15.638	18.361
Brownsford			
	38.195	15.618	18.173
	38.245	15.634	18.198
	38.232	15.628	18.196
Caim			
	38.094	15.628	17.912
	38.028	15.611	17.894
Clontibret (Stibnite)			
	37.965	15.526	17.925
	37.969	15.528	17.925
	38.020	15.540	17.937
	37.985	15.528	17.927

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