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An overview of the Glendalough mine site, from the Spink path, with adits and spoil heaps on the northern slope of the valley. The bare area on the valley floor is mostly spoil covered, but includes remains of water powered processing operations. (Photo by Matthew Parkes).

Iris don Iontaobhas um Oidhreacht Mhianadóireachta

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GEOLOGICAL SETTING OF THE LEAD-BEARING VEINS IN THE GLENDALOUGH-GLENDASAN DISTRICT, COUNTY WICKLOW

By Peadar McArdle

Abstract: The lead-bearing veins in the Glendalough-Glendasan district of County Wicklow occur along major fractures on the eastern margin of the Leinster Granite. The veins are typically 1-6m thick and are composed of galena-sphalerite-pyrite in a quartz-calcite gangue. The host granite has been brecciated and hydrothermally altered. The geological context and development of the veins is described in this paper. *Journal of the Mining Heritage Trust of Ireland*, **7**, 2007, 3-7.

INTRODUCTION

Prior to 1960, Wicklow was the premier mining county on the island of Ireland. This was based in part on the substantial production of copper and pyrite from the Avoca district. It also reflected the lead output from several veins along the eastern margins of the Wicklow Mountains and centred around Glendalough. In these circumstances it is not surprising that one of the earliest county geological maps completed in Ireland was for County Wicklow.

That map was published in 1801 by Robert Fraser and it shows the distribution of rock types across County Wicklow. It colour codes the various types of rocks wherever they are exposed. The pink areas are granite, principally forming the mountains. The low ground on either side is composed of slaty sediment, shown in blue colour. The Avoca mining ("metalliferous") district, now known to be underlain by volcanic rocks, extends from Avondale to Croghan Kinshelagh Mountain at the county boundary and is shown in golden shade. The quartzites around Bray Head feature in brown colour. The lowest ground, especially in the west, has a greenish tint and represents boulder clays derived specifically from the limestones of the Irish midlands. The main rock types as we know them today are all represented although they are not shown in the same resolution as today's modern geological maps (for example, Mc Connell *et al.* 1994).

The rock sequence containing the lead-bearing veins of County Wicklow is entirely at least 400 million years old and it records the plate tectonic history of the Earth's crust over the period 535-400 million years ago (Max *et al.*1990). This history comprises the events of the Caledonian Orogeny: this involved the opening of an extensive Iapetus Ocean in the period to about 480 million years ago and then its contraction and elimination down to about 430 million years ago. In all of this time, Wicklow was situated on the southern (Avalonian) margin of this ocean. Following its destruction, opposing plates collided with each other, leading to the deformation and metamorphism of the rocks of both margins as well as the emplacement of granites such as the Leinster Granite. The bedrock history of Wicklow effectively finished around 400 Ma when the Leinster Granite was emplaced and cooled down. Over the period of this evolution the area of Wicklow migrated from the high southern latitudes to about 30°S. More of this fascinating history can be found in references such as Cocks and Torsvik (2006).

SLATES AND SCHISTS

The rock sequence of County Wicklow occurs in the Caledonian terrain and is composed of Cambrian to Silurian marine sediments which contain some developments of volcanic rocks (Figure 1). The mountainous core of the county is dominated by the early Devonian Leinster Granite. To the west the sediments are unconformably overlain by, or faulted against, post-Caledonian sandstones and limestones of Devonian and Carboniferous age.

Four major rock groups are recognised in the Cambrian-Silurian rock sequence of this district. The oldest, the Bray group of Cambrian age, comprises greywackes, slates and quartzites which formed in a marine environment. The greywackes are green sandstones with varied amounts of muddy matrix (well exposed on the N11 north of the Rathnew exit). They, along with much of the other sediments, formed from turbidity currents, sediment-charged bodies of seawater generated by storms and earthquakes which surged down even the gentlest of slopes. The greywacke was formed from mixtures of sand and mud, the quartzite from sand and mudstone from mud. The distinctive fossil *Oldhamia*, consisting of animal traces in muddy sediment, is found at Bray Head.

The succeeding Ribband Group rocks are the most widespread and are Cambrian to Ordovician in age. They are closely associated with the lead-bearing veins that were mined in Wicklow. They consist mainly of fine grained sedimentary rocks, slates, siltstones and sandstones which were deposited as silt and mud from turbidity currents in deep seawater. These included the manganese-rich sediments called coticules. Deposition took place on a deeper and more remote seafloor than in the case of the Bray Group. The tectonic plate movements which caused this evolution in the Iapetus Ocean also gave rise to volcanic activity, and basalts and andesites are preserved as relatively small developments in several areas.

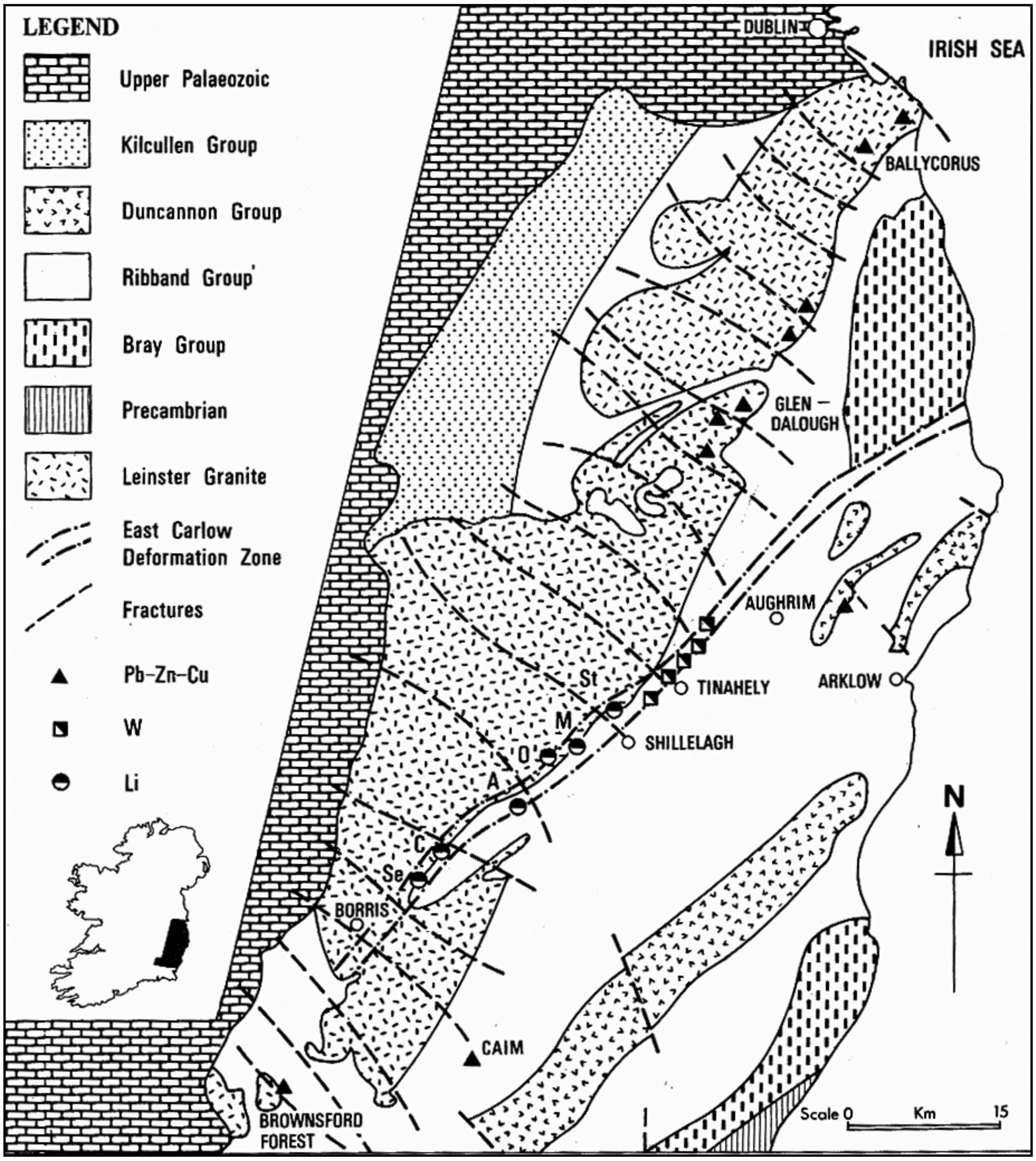

Figure 1. Geological setting of mineral deposits in southeast Ireland. From Kennan et al. (1986).

The next group, the Duncannon Group, is Ordovician in age and composed of a variety of volcanic rocks with only minor sediments. These are, as in the case of Ribband Group volcanic rocks, the products of continuing subduction and destruction of Iapetus Ocean. They originated from chains of volcanoes, or volcanic arcs, which were deposited beneath seawater. These are hosts to the economically important copper deposits which were mined extensively around Avoca. Sediments of the Duncannon and Ribband Groups locally contain preserved fossils which have been used to date them and these consist especially of graptolites, brachiopods and trilobites.

The youngest group of rocks, the Kilcullen Group, is Silurian in age and is exposed to the west of the Leinster Granite. The rocks are dominantly of green greywackes. They bear similarities to the greywackes of the older Bray Group.

Sedimentation ceased when opposing sides of the Iapetus Ocean collided with each other about 430 million years ago and the seafloor was entirely consumed by subduction. Continued collision led to one plate overriding the other, leading to mountain building and the climax of the Caledonian Orogeny. The sediments were compressed and a new cleavage imposed on the muddy ones (due to the realignment and recrystallisation of mud flakes). The rocks were also extensively crumpled and faulted on all scales. The base of the overridden plate sank to a depth where partial melting occurred and liquid granite magma ascended in the crust to cool and form granite bodies. The movement of magma was often facilitated by the presence of major fault zones. The heat from the granite baked the slates it intruded and metamorphosed them to schists containing newly formed minerals such as andalusite and garnet. This, and the related formation of lead-bearing veins, was the final act of the Caledonian Orogeny.

GRANITE

Granite is a very distinctive and familiar rock type to many people because it is commonly used in construction. Several quarries exist in the Leinster Granite, situated especially in South Dublin and North Wicklow, although few are still actually producing. Although the granite forms an upland area its rounded hills have few exposures but the deeply incised valleys and corries are locally well exposed.

The Leinster Granite stretches from the coastline at Dun Laoghaire to the vicinity of New Ross, covering an area in excess of 1500 sq km. It is the largest granite body in this part of Europe and comprises five individual units, or plutons. Each is circular or oval in shape and traditionally was viewed as a cross-section through a deep-going body with the shape of an inverted teardrop. The individual plutons are contiguous to each other and arranged in a northeast-southwest direction. They have been emplaced along the cleavage of the surrounding slates during a period of extensive shearing. Intrusion has been dated as 405+/- 2 million years ago. There are a series of northwest-trending fractures cutting the granite at regular intervals some of which may have controlled granite intrusion and also influenced the location of lead-bearing veins.

The granite has a uniform composition over large areas and three main varieties have been recognised in the district with lead-bearing veins. The most extensive granite varieties are of coarse grained adamellite and are called Type 2 granites. Equigranular and porphyritic microcline varieties are distinguished from each other because the latter contains large crystals of microcline. The third variety is fine grained granodiorite and is biotite rich. There are also muscovite-rich coarse grained granites which are modified variants of these main varieties. There is a fairly widespread occurrence of narrow dykes in the granite. Aplite and pegmatite dykes both have the same mineral composition as granite but the former is uniformly fine grained (with noticeably little biotite) while the latter is very coarse grained. There are also quartz veins, some of which are sufficiently extensive to have supported quarrying in the past.

The roof of the Leinster Granite is known from the summit of Lugnaquillia where its contact is flat. The flanks of the granite tend to dip outwards at moderate or steep angles, such as those well exposed at Lough Ouler or Glendalough. Given the circular or oval outcrop pattern, this supported the interpretation that the granite represented the top of an individual inverted teardrop. Granite originates as a molten magma at depth in the Earth's crust and ascends through the crust until it cools and solidifies. Textbooks show diagrams where major granites ascend from a zone of plate collision - in principle similar to the situation in Wicklow. It is estimated that the granite formed at a depth of 35km and temperature of 650°C. It cooled gradually as it ascended and finally crystallised at a depth of 5-10km below surface.

There have been few recent research articles on the origin of the Leinster Granite but elsewhere there has been considerable progress concerning the development of plutons. Geophysical evidence suggests that many plutons do not have the necessary depth associated with a tear-drop shape. Also no evidence has been found of significant volumes of liquid magma in areas where they might be expected (for example, beneath volcanoes). Newer evidence has suggested that granite has accumulated gradually, with small volumes repeatedly moving upwards along narrow fractures. Thus granite assembled incrementally in low-stress zones - and often formed flat-lying sheets with relatively little depth. In the case of the Leinster Granite, if this process is confirmed here, the magma may have used some of the northeast-southwest trending shear zones. The Leinster Granite does contain areas of sheeted granite which would support this alternative view of its development. The granites of Donegal have received much attention in recent decades, involving this recent interpretation, and the interested reader is referred to the seminal work of Pitcher (for example, Pitcher and Hutton 2003).

MINERAL DEPOSITS

There is a variety of metallic mineral deposits in the Caledonide rocks of southeast Ireland (Figure 1). Only that at Avoca has supported modern mine operations although historical production on a small scale is reported from many localities (Cole 1922). The Ribband Group rocks have the greatest variety of deposits: lithium, tungsten, lead and zinc deposits occur either in Ribband Group rocks themselves or in intrusions emplaced within them. In contrast the volcanic rocks of the Duncannon Group are characterised by copper and minor gold mineralisation. Minor uranium occurrences are also known from the Leinster Granite.

The lead-bearing veins of southeast Ireland (Cole 1922) are largely concentrated in County Wicklow but they also occur elsewhere. They are a feature both of the Leinster Granite and the Ribband Group. In the Leinster Granite they are confined to its eastern margin. The veins are composed of galena, sphalerite and pyrite in a quartz-calcite gangue. Many veins show evidence of brecciation and are associated with hydrothermally altered granite. The examples in the Ribband Group are both outlying, at Caim and Barrystown, County Wexford.

The Wicklow lead-bearing veins all occur in granite where it has been brecciated and hydrothermally altered. They are typically situated along the courses of major fracture zones. They are most common in areas of the granite margin where coticule and tourmaline-bearing schists of the specific Maulin Formation (Ribband Group) form the aureole rocks. Elsewhere, where these lithologies are absent, no mineralised veins have been discovered.

The coticules form thin layers individually less than 2cm thick and they are characterised by complex folding which formed while the sediments were still soft. They comprise quartz-rich layers which stand out on outcrop against the more easily weathered slates. They contain fine grained spessartine garnets, locally giving the layers a pinkish hue, which typically make up 50% of their volume. Tourmalinites, containing over 25% tourmaline, are characterised by abundant black tourmaline crystals. They form along the edges of quartz veins and interbedded with coticules, as well as being interbedded with other sediments. The tourmalines have a schorl-dravite composition unlike the schorl composition typical of tourmaline associated with granite. These unusual rock types were metal-bearing deepwater sediments which developed on the ocean floor around vents of super-heated water - perhaps the "Black Smokers" of the ancient ocean.

Kennan (1978) described the spatial association of coticules and lead-bearing veins along the eastern margin of the Leinster Granite. These veins are also restricted to granite that is hydrothermally altered. This alteration is not pervasive in the

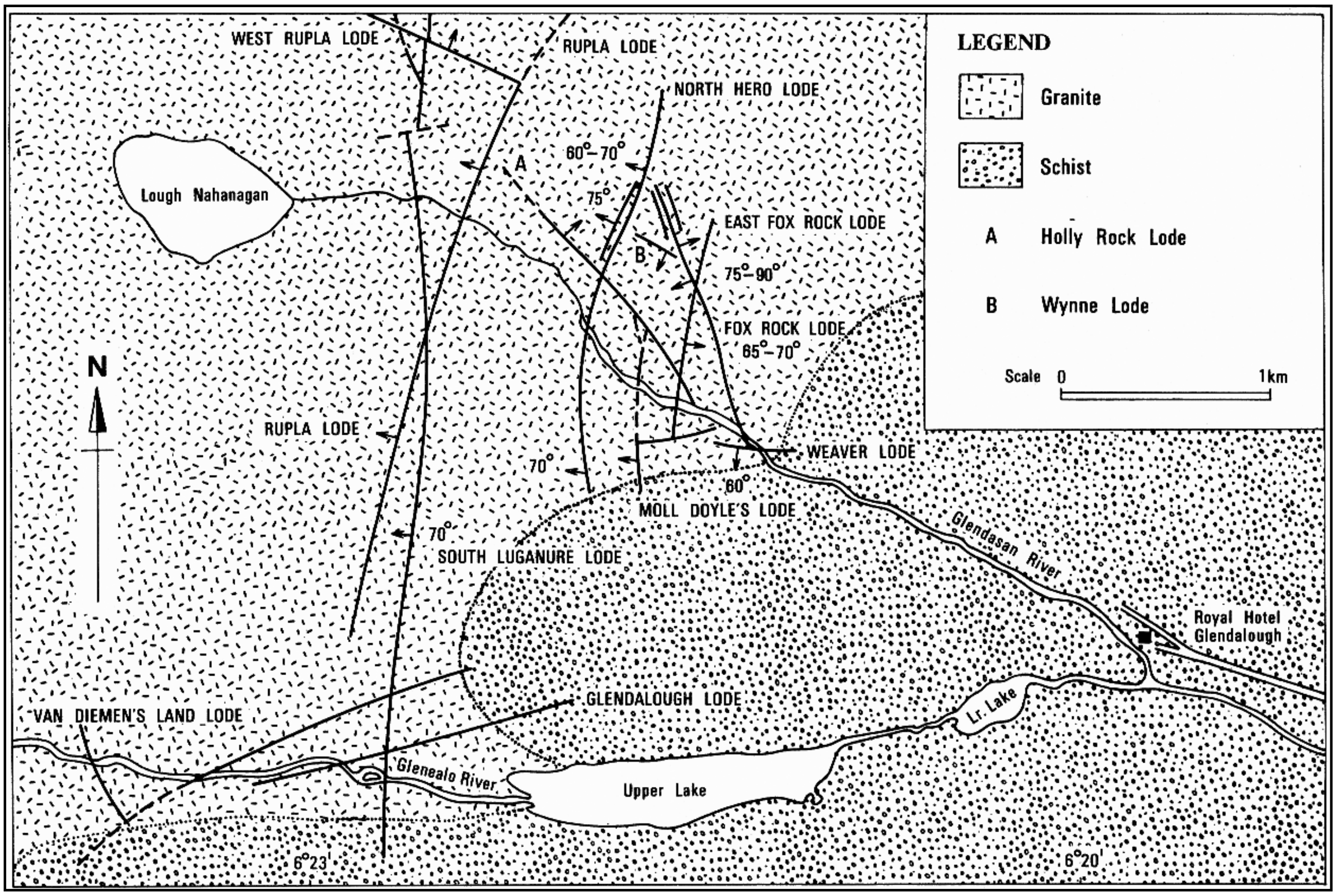

Figure 2. Orientation and distribution of lead-bearing veins in the Glendalough-Glendasan district, County Wicklow. From Kennan et al. (1986).

Leinster Granite but seems to be related to a series of transverse fracture zones identified on satellite imagery by Brück and O'Connor (1980). The alteration takes two forms. In places it involves the replacement of plagioclase by calcite and of biotite by chlorite. Elsewhere the development of haematite produces distinctively reddened granite and pegmatite. The areas of transverse fractures also have explosion breccias which formed during the cooling and alteration of the granite.

The main development of lead-bearing veins occurs in the Glendalough-Glendasan area (Figure 2). There are lesser veins further to the northeast (Lough Dan, Lough Tay, Ballycorus, Killiney) and the southwest (Glenmalure and, more remotely, Brownsford Forest at the southwestern extremity of the Leinster Granite). In the Glendalough-Glendasan area the major veins are steep and trend approximately north-south. Another set of veins trends between east-northeast and northeast, while others, east-west veins called cross-courses, are best developed at Glendalough. Veins are typically 1-6m thick and locally attain 12m. Some veins follow earlier pegmatite dykes.

The lead-bearing veins developed at a late stage in the history of the Leinster Granite. Deposition of sulphides occurred following several episodes of brecciation and hydraulic fracturing. The main sulphides are galena and sphalerite, with lesser chalcopyrite and pyrite, and set in a matrix of quartz, calcite and barite. Galena contains minor silver which was recovered during smelting.

DEVELOPMENT OF THE LEAD-BEARING VEINS

There are a variety of geological controls on the occurrence and distribution of lead-bearing veins in the Glendalough district. The most obvious control is the Leinster Granite: all the deposits are hosted within it, although they are by means uniformly distributed throughout it. They are confined to a specific granite type along the eastern margin of its two northerly plutons. The granite in their vicinity is commonly altered, weathered and brecciated.

Another significant geological control is that the lead-bearing veins are restricted to those marginal parts of the Leinster Granite that are in contact with the Maulin Formation (Ribband Group) where it contains coticules and tourmalinites. Kennan (1978) suggested that the source of the metals might be in the granite aureole and subsequent research (Doyle 1985) supports their derivation from coticule-bearing rock sequences.

Another control on the distribution of lead-bearing veins is the series of transverse fractures where they intersect the granite margin. These fractures are altered and weathered, suggesting that they acted as selective channelways for circulating groundwater and that they controlled the siting of the lead-bearing veins.

In summary a two-fold mechanism for concentrating metals in the Glendalough veins is proposed. This concept was originated by Kennan (1978) and was subsequently developed by him and his co-workers (for example, Doyle 1985, Williams and Kennan 1983, McArdle *et al.*, 1986). Hydrothermal fluids on the Ordovician seafloor gave rise to a sequence of coticule-bearing sediments which were enriched in metals, including lead and zinc. In the early Devonian the Leinster Granite was emplaced beneath the surface and in its later stages of cooling a convective system was established on its margins whereby warm fluids derived metals from the metal-bearing sequence and carried them into the transverse fractures of the granite. There they were deposited due to the changed chemistry of the wall rocks.

EXHUMING THE VEINS

Human activity has led to the extraction of economic quantities of lead ores from the Glendalough veins over the past 200 years. However the veins formed at a depth below surface of 5-10km, a depth that would have been entirely impractical for mining over this period. It was the geological processes that led to the exhumation and erosion of this landscape that exposed the veins at surface and made their extraction feasible. Accordingly these processes form the final step in the geological setting of the Glendalough lead-bearing veins.

The Leinster Granite was first exposed some 350 million years ago when Old Red Sandstones of Devonian age were deposited on the freshly exposed granite. There is evidence that the Wicklow region was hilly at this time and that this landscape persisted for a considerable period. About 75 million years ago, in a greenhouse climatic period, Wicklow had subdued or relatively flat topography which was inundated by rising sea levels. Sea levels would have been 200-300m above present levels on a world-wide basis, in response to major plate tectonic events. Chalk deposits would have formed extensively in this environment only to be eroded away subsequently.

A variety of evidence is available to establish that the subsequent uplift of the Wicklow Mountains occurred between 36 and 10 million years ago. This uplift was the result of the region's active seismic history, a history that is still charted in modern times by the seismic researches of the Dublin Institute for Advanced Studies, which demonstrate that this region is more prone than any other in Ireland to minor earthquakes. This story of landscape evolution, inspired by the pioneering work of Frank Mitchell and Adrian Phillips, is summarised by Allen *et al.* (2002). Only the glacial sculpting of the Quaternary Ice Age modified it significantly, providing the steep valley walls where veins could be feasibly mined. The entry of humans into the story brings my part of it to a close.

REFERENCES

ALLEN, P.A. and others. 2002. The post-Variscan thermal and denudational history of Ireland. In:DORÉ, A., CARTWRIGHT, J., STOKER, M., TURNER, J. and WHITE, N. (Eds) Exhumation of the North Atlantic Margin: Timing, Mechanisms amd Implications for Petroleum Exploration. Geological Society of London Special Publication 196, 371-399.

BRÜCK,P.M. and O'CONNOR,P.J. 1980. Major transverse and other linears in the Leinster Granite. *Geological Survey of Ireland Bulletin* **2**, 349-370.

COCKS, L.R.M. and TORSVIK, T.H. 2006. European geography in a global context from the Vendian to the end of the Palaeozoic. In: GEE, D.G. and STEPHENSON, R.A. (Eds), European Lithosphere Dynamics. Geological Society, London Memoirs 32, 83-95.

COLE, G.A.J. 1922. *Memoir and map of localities of minerals of economic importance and metalliferous mines in Ireland*. Geological Survey of Ireland Memoir.154 pages.

DOYLE, E.M. 1985. The coticule rocks of the Lower Palaeozoic Maulin Formation in southeast Ireland. Unpublished Ph.D. Thesis, National University of Ireland.561 pages.

KENNAN, P.S. 1978. The origin of the sulphide deposits in the Leinster Granite. *Journal of Earth Sciences, Royal Dublin Society* **1**, 41-47.

KENNAN, P.S., McARDLE, P., WILLIAMS, F.M. and DOYLE, E.M. 1986. A review of metal deposits associated with the Leinster Granite and a model for their genesis. In: Andrew, C.J., Crowe, R.W., Finlay, S., Pennell, W. and Pyne, J.F. (Eds). Geology and Genesis of Mineral Deposits in Ireland. Irish Association for Economic Geology, 201-210.

MAX, M.D., BARBER, A.J. and MARTINEZ, J. 1990. Terrane assemblage of the Leinster Massif, SE Ireland, during the Lower Palaeozoic. *Journal of the Geological Society of London* **147**, 1035-1050.

McARDLE, P., WILLIAMS, F.M., DOYLE, E.M., KENNAN, P.S., MOORE-LEWY, G., GALLAGHER, V. and O'CONNOR, P.J. 1986. The metallogenic relationships of mineralisation along the southeast margin of the Leinster Granite. Geological Survey of Ireland Report Series RS 86/2 (Mineral Resources). 57 pages.

Mc CONNELL, B., PHILCOX, M.E., SLEEMAN, A.G., STANLEY, G., FLEGG, A.M., DALY, E.P. and WARREN, W.P. 1994. Geology of Kildare-Wicklow. A geological description to accompany the Bedrock Geology 1:100,000 map series, Sheet 16. Geological Survey of Ireland, 69 pages.

PITCHER, W.S. and HUTTON, D.H.W. 2003. *A master class guide to the granites of Donegal*. Geological Survey of Ireland. 97 pages.

WILLIAMS, F.M. and KENNAN, P.S. 1983. Stable isotope studies of sulphide mineralisation on the Leinster Granite margin and some observations on its relationship to coticule and tourmalinite rocks in the aureole. *Mineralium Deposita* **18**, 399-410.