CONNACHT COALFIELD

Background information

Mine District: Connacht Coalfield

Mine Names: Bencroy, Derreenavoggy, Geevagh, Gubbarudda, Rockhill, Rover, Spion Kop

Elements of interest:
Ni, Zn, SO_4, acidity

Project Prefix: CC-

County:	Townland:	Grid Reference:
Leitrim, Roscommon, Sligo	Various	E193000, N314000

Introduction

The Connacht Coalfield is located in the hills east and west of Lough Allen, mainly in counties Leitrim and Roscommon but with also in Cavan and Sligo (Fig. 1). The coals seams are within a hard Upper Carboniferous Namurian sandstone that forms a resistant cap above softer limestone-dominated succession of the Lower Carboniferous in the surrounding lowlands. The many streams draining the uplands flow into Lough Allen or the Shannon River and its tributaries.

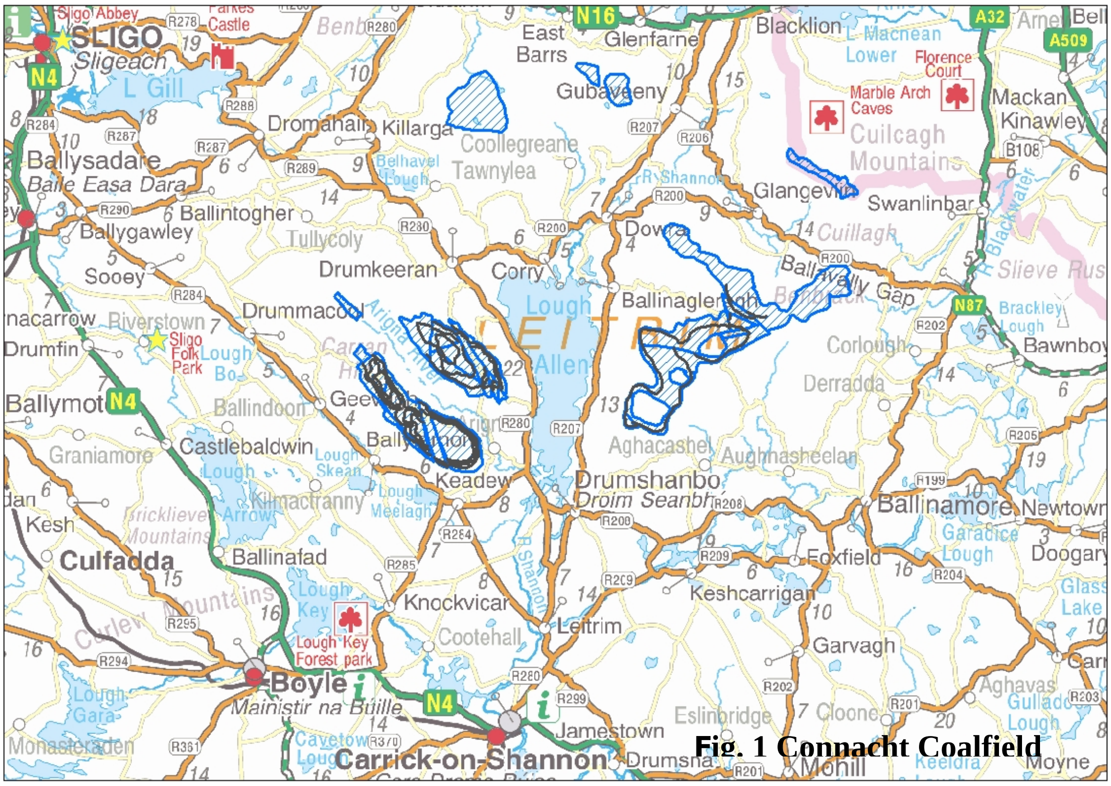

Fig. 1 Connacht Coalfield

Most coal mining has taken place west of Lough Allen on Kilronan and Altagowlan Mountains. To the east of the lake, less intensive mining took place at Bencroy on Sliabh an Iarainn. The latter means "Mountain of Iron" in Irish, a reference to the iron deposits that were originally exploited long before any coal was mined in the district. The iron occurs as iron-rich nodules in the coal-bearing succession throughout the coalfield.

The land around the coal mines is upland bog and grassland, used mainly for sheep and cattle grazing and for forestry. Much of the area is remote and very sparsely populated, with the village of Arigna the only significant settlement within the coalfield itself. Drumshanbo is the nearest town. In recent years, wind farms have been constructed on both Kilronan and Altagowlan. One former colliery at Derreenavoggy has been reopened as a tourist mine and is an important attraction for visitors to the region.

The main coal seam was discovered on Kilronan above Arigna in 1765 and coal mining began, initially as means of fuelling furnaces for iron smelting. It would continue until 1990, in later years supplying fuel to an electricity station that was built in order to support the mining industry. The coal seams are inclined at a very low angle (5º or less) within the sandstone and were exploited from adits driven at various points along the outcrop of the seam. Flooding was not a major problem and there was no great need for engines to pump out the underground workings or to raise ore. Thus the 19th-century engine houses and chimneys that are part of the landscape in the Slieve Ardagh coalfield are entirely absent in Connacht. The only pre-20th-century building of note is the blast furnace house at Creevelea, where iron ore was smelted in the mid 19th-century using coal. Most of the mining features preserved in the district date from the 20th century: several opencast excavations, numerous adits and shafts, large waste heaps and some mine buildings.

Geology and Mineralization

The Connacht Coalfield, like the Leinster and Slieve Ardagh Coalfields, is hosted by an outlier (younger rocks surrounded by stratigraphically underlying older rocks) of Upper Carboniferous sandstones, siltstones and shales that sit on the surrounding Lower Carboniferous limestones. However, the coal seams in Connacht differ from those of the other two coalfields in that they are hosted exclusively by Namurian rather than younger Westphalian strata. The coal is within one formation, the Lackagh Sandstone Formation, a cyclothemic formation in which thick-bedded channel sandstones are interbedded with mudstones, siltstones and fine sandstones (MacDermot *et al*. 1996). Five coal seams occur in the Arigna area (Kilronan and Altagowlan). Each cyclothemic unit commences with mudstones and siltstones, the products of river flooding, and nodules of sideritic ironstone are common (McArdle 1992). The fine sediments are followed by a coarsening-upwards succession of sandstone with, at the top, *in-situ* plant rootlets, i.e. seatearths. The sandstone and seatearths represent channel infill. Coal seams form the top of each cyclothem (McArdle 1992). Seams are typically 0.3 to 0.9m thick.

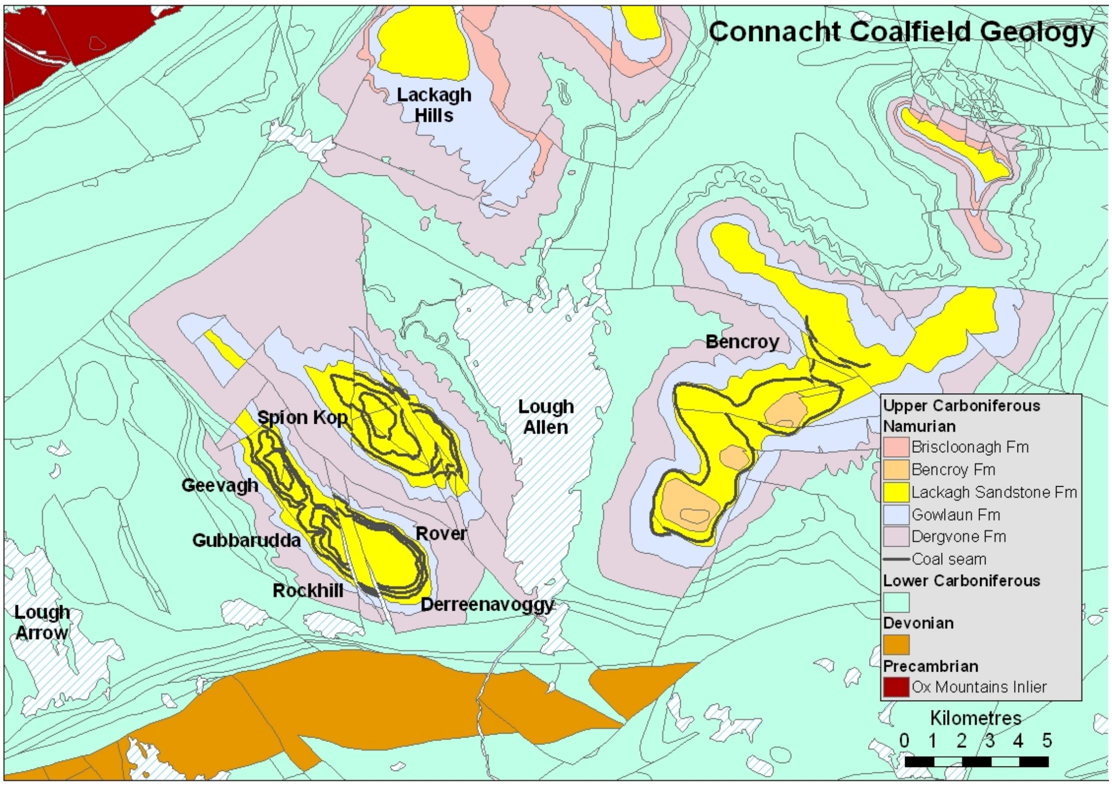

Fig. 2 Connacht Coalfield: general geology and colliery locations

The five seams identified and correlated across the coalfield (McArdle 1992) are, starting with the lowermost one, Lower Crow Coal, the Middle Crow Coal, the Upper Crow Coal, the Main Coal and the Top Coal. The latter two seams are now entirely worked out. McArdle (1992) provides quality data for those seams that still have some resources – data for the Kilronan-Altagowlan area are reproduced in Table 1. The coal in the Connacht Coalfield is bituminous, with a lower calorific content than the anthracite of Slieve Ardagh and the Leinster Coalfield. Ash content can be very high, in excess of 50%, but sulphur content is typically only 0.5%. The high ash content was a barrier to establishing a market for the coal – the power plant burned Lower Crow Coal (20% ash) blended with Main Coal but when the Main Coal was exhausted, it was not possible to use the Lower Crow Coal alone (McArdle 1992). Around 7.5 Mt of coal resources remain in Kilronan-Altagowlan. Even greater resources are potentially available east of Lough Allen on Sliabh an Iarainn, where sub-economic resources of coal with 48% ash content were calculated to be almost 20 Mt (McArdle 1992). Coal has never been exploited to the same degree east of Lough Allen, possibly because of the remoteness of the area. A further 1.4 Mt are estimated to be present north of Lough Allen in the Lackagh Hills (Fig. 1).

Table 1 Connacht Coalfield seam quality and resources (west of Lough Allen)

Seam	Height, m	Calorific Value kcal/kg	S %	Ash %	Sub-economic resources, Mt
Top Coal	≤0.30	-	-	-	-
Main Coal	0.36-0.56	-	-	-	-
Upper Crow Coal	0.15-1.04	n.a.	~0.5	>30	0.74
Middle Crow Coal	0.05-1.33	4000	~0.5	50	4.23
Lower Crow Coal	≤0.56	5500	~0.5	20	2.50

From McArdle (1992)

Mining History and Production

In the early 17th century, Sir Charles Coote brought in English and Dutch miners to exploit the iron deposits of the area around Lough Allen, establishing a smelter at Creevelea. The iron industry continued until the mid 18th century on the small scale that was common throughout Europe, with timber from local forests providing fuel for what was essentially a local industry. The best ore occurred on Sliabh an Iarainn, east of Lough Allen. Nodules were washed down in streams to the lakeshore where local people gathered them and carted them to the furnaces. However, the iron industry went into decline as intensification of agriculture led to land clearances and the disappearance of forests, a pattern repeated across Europe. The development in Britain in the early 18th century of the coking process that allowed coal to be used for smelting iron ore reversed this decline and created the basis for the industrial revolution. Four key elements underpinned the new iron industry in Britain: iron ore, coal for fuel, sandstone for use as a refractory lining in furnaces and limestone for use as a flux. All were found together in the Lough Allen area, opening up the possibility of similar industrial development in Ireland.

In 1765, the Main Coal seam was discovered in the hills above Arigna village, west of Lough Allen. Hopes that this would lead to sustained development in the west of Ireland, based on steel manufacture, proved unfounded. Various attempts were made to develop sustainable foundries but ultimately all fell foul of competition from Britain. In 1852, at Creevelea, a Scottish company spent large sums on blast furnaces, an engine house, roasting and coking kilns and ancillary buildings. Coal was carted from Knockateen, 12 km away, and the cost of doing so was probably what led to bankruptcy within two years, despite the company's technical success in producing and exporting good-quality iron. By 1866, Creevelea was making good profits but a fall in the price of iron led to the final closure by 1872.

Creevelea was the last attempt to exploit the iron deposits of the Lough Allen area but coal mining would continue until the end of the 20th century. For most of their production life, the region's collieries supplied local needs, chiefly heating fuel for houses, schools and hospitals. The remoteness of the area from major markets and the poor transport infrastructure, factors that had critically undermined the nascent iron industry, also prevented the coal industry from achieving more prominence than it did. The coal was friable in nature and could not survive long transport on poor roads. When the government finally constructed a narrow-gauge railway link to Arigna in 1920, the line fell short of requirements, as it had neither sufficient wagons nor engines to transport coal regularly. There were more orders from cities like Limerick than could be met – enough coal was mined but, for lack of transport, it could be left deteriorating in bad weather on the hillsides around Arigna. Ultimately, the state electricity company, the ESB, solved this problem by constructing a coal-fired power station at Arigna. Opened in 1958, the station was essentially a means of preserving the mining jobs in the district. At its peak it took 85% of Arigna's coal. During the 1980s output was around 50,000 tpa, around 75 to 90% of annual national coal production. Production took place almost exclusively west of Lough Allen, with mining from both underground and opencast operations run chiefly by Arigna Collieries Ltd. and Flynn and Lehany Coalmines Ltd. (McArdle 1992). The power station stopped purchasing coal in mid-1990 and, with no market for its product, mining ceased shortly afterwards.

No estimate of total production in the coalfield has been published. Records of production in the 18th and 19th centuries are not generally available. Nevertheless, overall production must have been substantial given that it was carried on almost continuously for over 150 years, albeit tempered by the poor transport networks that made development of non-local markets difficult.

Site Descriptions and Environmental Settings

There were numerous excavations within the Connacht Coalfield, extending over large areas on the surface and underground. In selecting sites in the coalfield for investigation as part of the HMS-IRC project, the main criterion considered was the presence of either solid or liquid mine waste on the site. For the purpose of the HMS-IRC project, seven areas have been defined that encompass the mine features studied and broadly correspond to the main collieries worked: Derreenavoggy, Rover, Rockhill, Gubbarudda and Geevagh on Kilronan, Spion Kop (Altagowlan) and Bencroy on Sliabh an Iarainn (Fig. 2). The Lackagh Hills was not investigated. Fig. 3 shows the extent of underground and surface workings east and west of Lough Allen, as established from mine records in GSI, together with individual names of collieries.

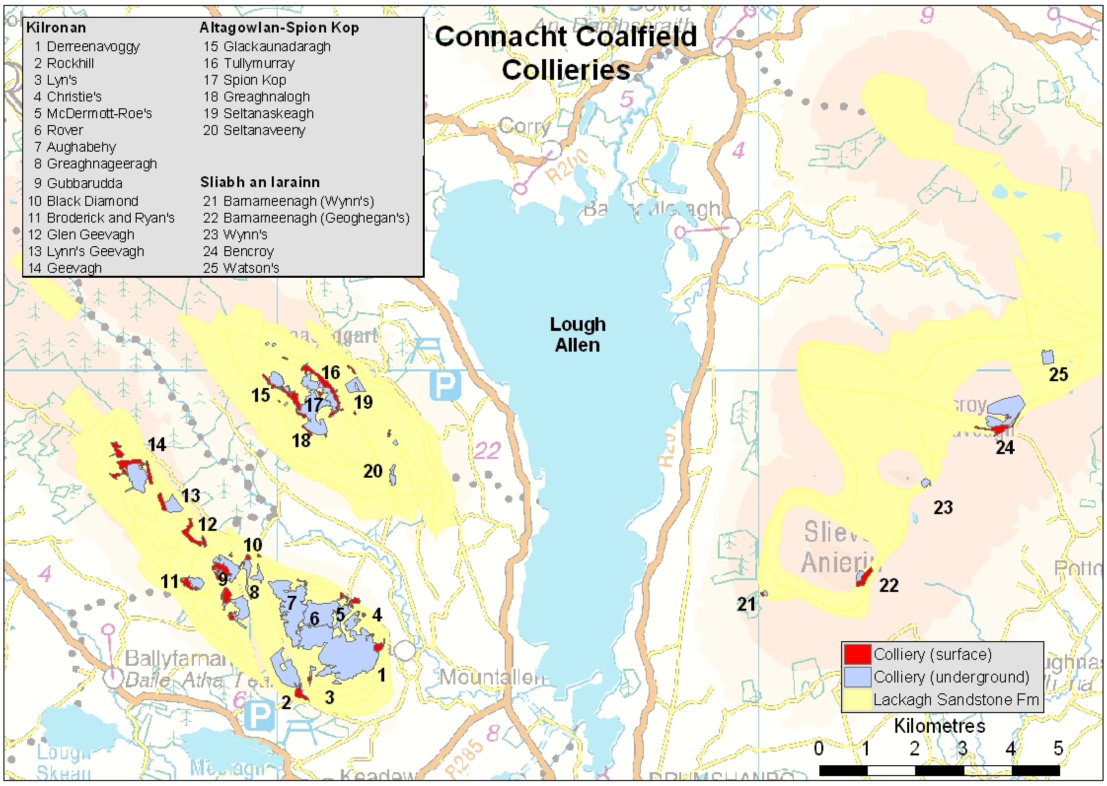

Fig. 3 Locations of known collieries in the Connacht Coalfield

The geochemistry of the Connacht Coalfield district is considered as a whole in the geochemistry section (below) rather than on a site-by-site basis. Individual site descriptions in this section review the main features of each site examined. Fig. 4 shows all the shafts, adits and levels originally compiled from the various historic sources available. As is clear from this, the Connacht Coalfield district has been intensively explored and exploited. Of the many shafts, declines and adits shown on Fig. 4, however, only a small proportion can be seen today. Most have been filled in or covered by subsequent land reclamation. In contrast, the illustration of underground workings may understate their actual extent because of the unavailability in some cases of suitable colliery plans for compilation purposes.

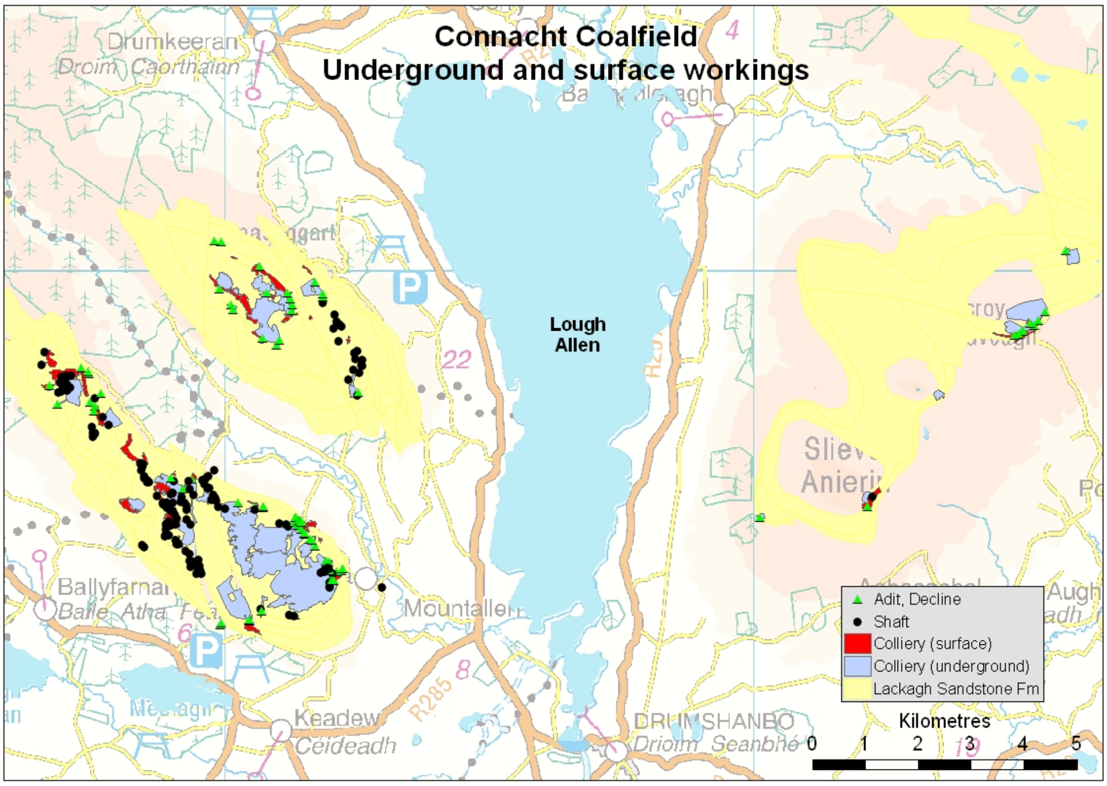

Fig. 4 Connacht Coalfield: distribution of shafts, adits and other mine workings

1. Derreenavoggy

Mine Name: Derreenavoggy

Alternative Name:

County: Roscommon

Townland: Derreenavoggy

Grid Reference: E192099, N314232

The Derreenavoggy colliery was mainly worked by Arigna Collieries in the period 1938 to 1962. However, mining continued in the 1970s further west and some of the adits marked on Fig. 5 were used as haulage routes. Derreenavoggy is now the site of a tourist mine and, as such, is unusual for a mine site in the number of visitors it receives. The museum operates from a custom-built building situated on the eastern flank of Kilronan Mountain, immediately overlooking Arigna village. The museum was built in front of the entrance to an adit. Above it on the hillside are several large solid waste heaps with steeply-dipping sides. The entire site, as drawn on Fig. 5, covers 14 ha and, in addition to the museum, contains several open adits some of which discharge mine water. The shafts marked on Fig. 5 are all backfilled.

The waste heap above the museum (SP01) was analysed *in situ* by XRF and is the only solid waste in the district to have been analysed. The data acquired for this heap have been applied to all other heaps in the district for the purpose of scoring the waste under the HMS-IRC Site Scoring system. Of the adits on the site, two discharge water (sampled at W064 and W028, Fig. 5) to the stream that flows east to the Arigna River. The adits at the northern end of the site are partly in-filled or collapsed; those beside the road leading up to the museum are more accessible, at least for a short distance (photo, above).

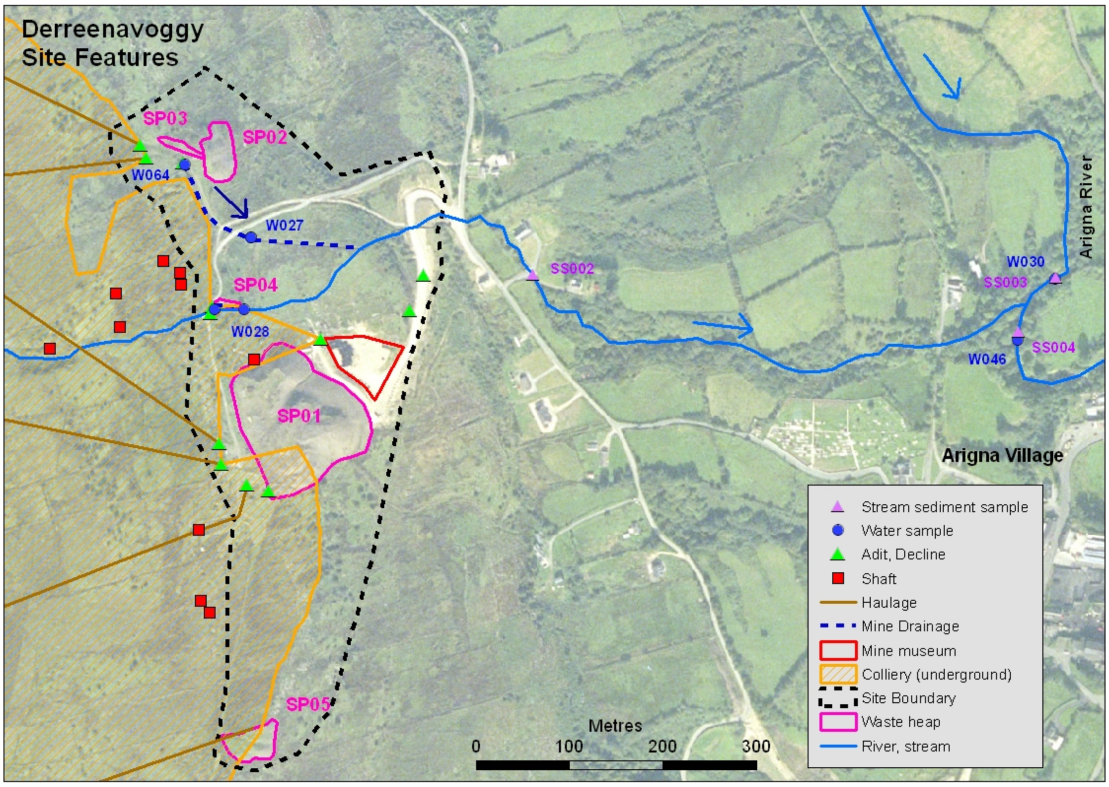

Fig 5 Derreenavoggy: mine features

Apart from the colliery waste, the main targets for geochemical investigation on the site were the surface water courses. Samples included drainage from two adits as well as stream sediments taken downstream of the adits. Water and stream sediments were sampled in the Arigna River upstream and downstream of its confluence with the stream draining Derreenavoggy (Fig. 5).

2. Rover

Mine Name: Rover

County: Roscommon

Townland: Kilronan Mountain; Rover Upper

Grid Reference: E191569, N315070

The Rover site incorporates several collieries on the northeastern side of Kilronan Mountain. The land here is used mainly for rough grazing. Several individual houses are located on either side of the road, close to the site. The collieries include Rover itself, operated between 1924 and 1938 by Arigna Collieries Ltd., McDermott Roe's Colliery, worked until 1938, and Christie's Colliery, which closed in 1947 (Fig. 6). Access to the collieries was by a series of adits running southwest from the main Arigna-Geevagh road. There are numerous surface traces of the collieries, including adits and solid waste heaps. Most of the latter are grassed over. Two adits discharges mine water, from Christie's colliery (sampled at W058, Fig. 6) and Rover colliery (W056). At Christie's colliery, the remains of what appears to be a crusher building can be found in front of the adit entrance, at the base of a waste heap (photo, above). The waste heaps were included in the HMS-IRC Site Scoring system by employing data for the waste heap (SP01) at Derreenavoggy. Because there is no individual chemical data for each waste heap, instead of scoring each of the waste heaps separately all the heaps were aggregated together and labelled SP06. The total area and volume of solid waste were used to obtain a single score for solid waste heaps at Rover.

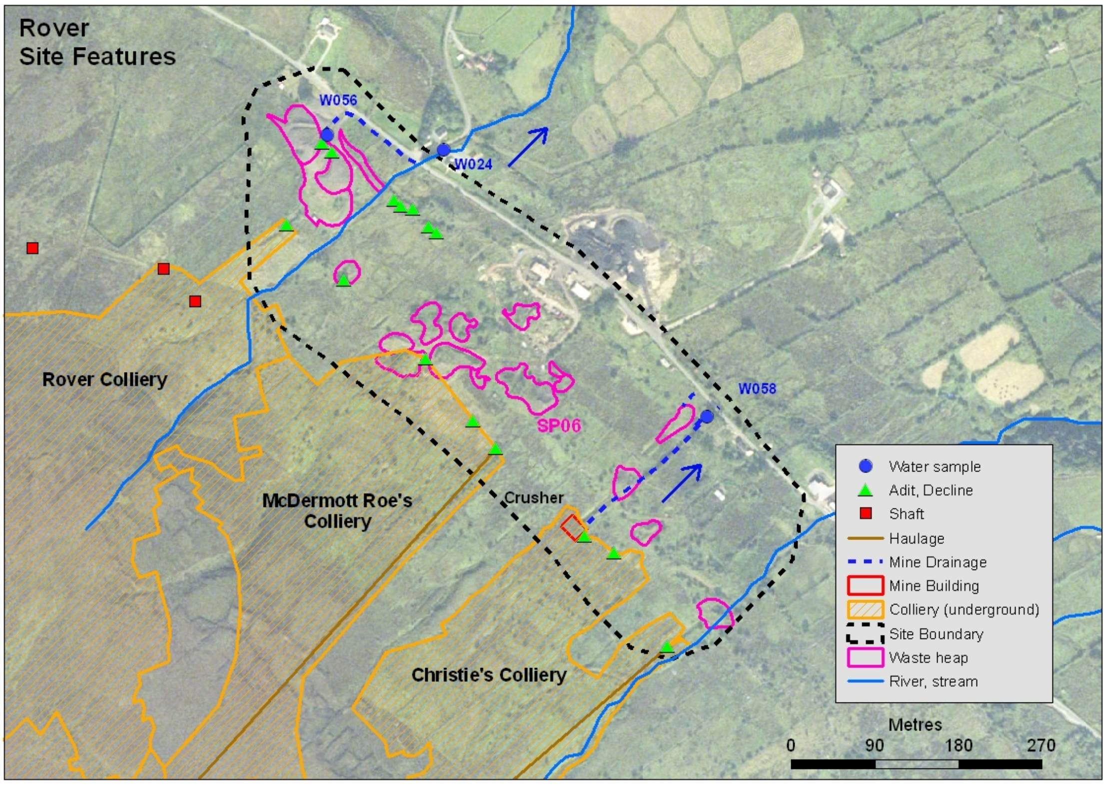

Fig. 6: Rover: mine features

3. Rockhill

Mine Name: Rockhill

County: Roscommon

Townland: Kilronan Mountain

Grid Reference: E190671, N313372

Rockhill Colliery is located on the southern flank of Kilronan Mountain. It was operated by Arigna Collieries Ltd. in the early part of the 20th century, ceasing in 1930. The site is below a recently constructed wind turbine farm. The site has several partly collapsed and filled-in adits and extensive solid waste heaps (Fig. 7). The site covers around 14 ha with the solid waste heaps defined on Fig. 7 accounting for 1.7 ha. Two mine water discharges combine on site and flow south under the dirt road leading up to the site. This road was apparently enlarged or refurbished during the construction of the windfarm and the wide area in front of the main gate is partly built on mine spoil. A small concrete mine building at the entrance to the site coincides with the mapped position of one adit.

Water samples (W067, W068) were taken below two adits and below the culvert through which the discharges flow beneath the road (W039) (Fig. 7). Flow rates below the discharge points were variable: the westernmost adit flowed at 3.4 l/s in winter, the easternmost one 0.4 l/s. The latter (W068) is the only one with significant metal content, having notably high Al (6287 ug/l), Ni (139 ug/l) and low pH (2.75). Both Al and Ni exceed the Draft EC Surface Water regulatory limits. This discharge flows over bare mine waste and this may account, in part, for the elevated metal contents and low pH. There is a large area of wetland on the site that is fed by the eastern discharge (W068) as well as by rainwater. It is the drainage from this wetland that combines with the western adit discharge (W067) to flow into the culvert.

As for Rover colliery, the waste heaps were included in the HMS-IRC Site Scoring system by employing data for the waste heap (SP01) at Derreenavoggy. Because there is no individual chemical data for each waste heap, instead of scoring each of the waste heaps separately all the heaps were aggregated together and labelled SP07. The total area and volume of solid waste were used to obtain a single score for solid waste heaps at Rockhill.

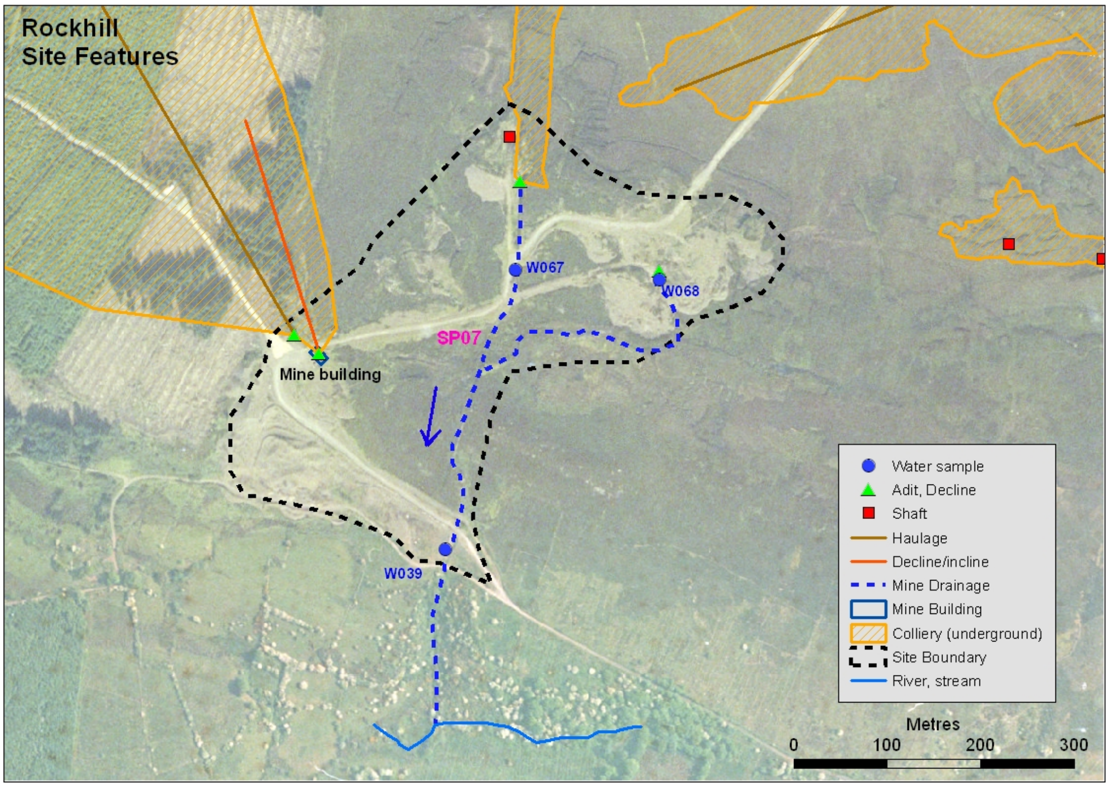

Fig. 7 Rockhill: mine features

4. Gubbarudda

Mine Name:	Gubbarudda
Counties:	Roscommon, Sligo
Townland:	Gubbarudda; Aghabehy
Grid Reference:	E189031, N315509

The Gubbarudda site as defined for this report is a very extensive area on the central part of Kilronan Mountain that was worked in a number of collieries over a period of at least a century until 1989. The last colliery worked was Flynn and Lehany's (marked "Gubbarudda" on Fig. 8) which operated between 1979 and 1989. This site, in particular, contains large volume of solid waste. The other collieries in the area included Broderick and Ryan's, abandoned in 1962, Greaghnageeragh, exhausted by 1955, and the Aghabehy Collieries in the eastern part of the area, which operated in the later part of the 19th century and the early 20th century (Fig. 8).

Some 70 shafts and adits are marked on Fig. 8, though most of these are filled in and have limited surface expression. Around 10 of the shafts and adits are open and accessible. The Greaghnageeragh mine site has some of the most extensive remains of mine buildings in the whole of the district, including workshops and a concrete gantry (photo, above right).

A limited number of water samples were collected on the site, including well water (W014, W015), low-pH water forming a pond on mine waste (W053) and an apparent adit discharge (W021) (Fig. 8). As was done for Rover and Rockhill collieries, the waste heaps were included in the HMS-IRC Site Scoring system by employing data for the waste heap (SP01) at Derreenavoggy. Because there is no individual chemical data for each waste heap, instead of scoring each of the waste heaps separately all the heaps were aggregated together and labelled SP08. The total area and volume of solid waste were used to obtain a single score for solid waste heaps at Gubbarudda.

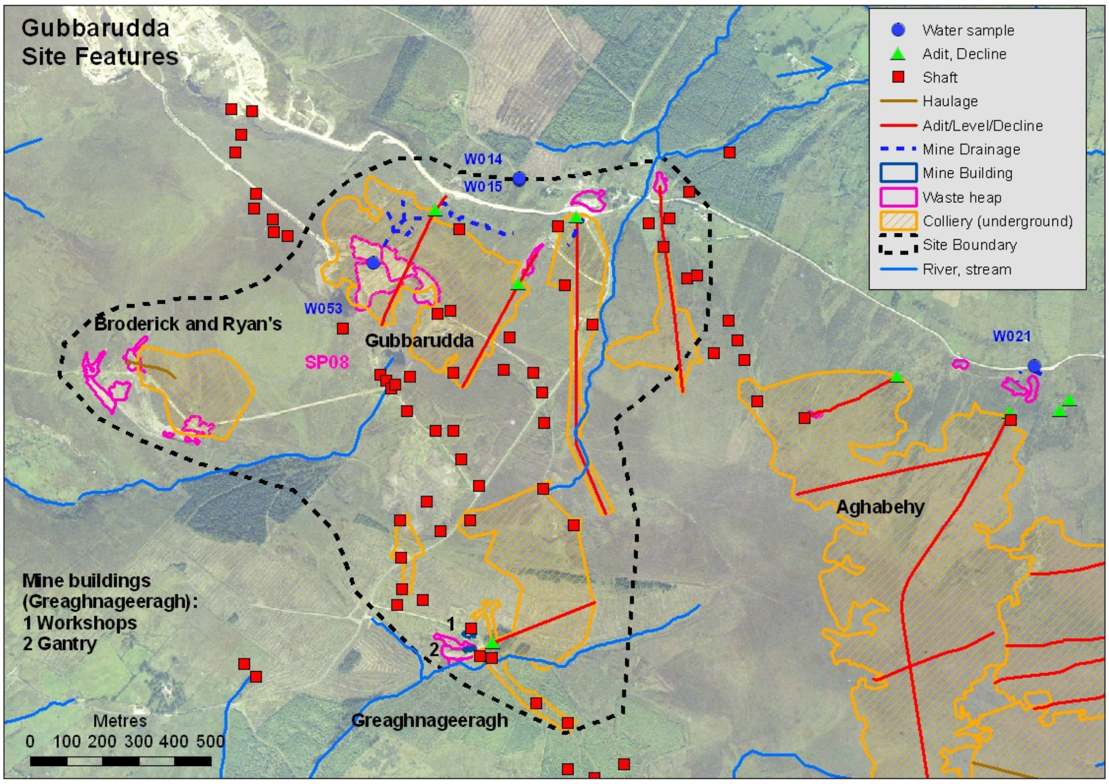

Fig. 8: Gubbarudda: mine features

5. Geevagh

Mine Name: Geevagh

County: Sligo

Townland: Ballynashee

Grid Reference: E187080, N317858

Geevagh is the westernmost site on the Kilronan Mountain ridge where it extends into county Sligo. It is located in a remote, exposed upland area of heathland adjacent to the minor road that crosses the mountain, linking Arigna and the village of Geevagh. Apart from some commercial forestry plantations, there is little evidence of activity in the area.

Geevagh was worked from two underground collieries, McTiernan's and Lynn's (Fig. 9). The former was operated in the 1960s and 1970s while the latter was worked in the 1930s before being abandoned in 1941. However, the most obvious expression of mining at Geevagh are the open pits (photo, above) and associated waste heaps that extend around the mountain side. The open pits are not shown on Fig. 9 but the waste heaps help define their location. In recent years, the pits have become a focus for illegal dumping of domestic rubbish (photo, left).

As is the case on other colliery sites in the Connacht Coalfield, most of the shafts and adits marked on the map are either backfilled or collapsed, leaving little or no trace. However, two adits are open: McTiernan's Incline (photo, right), just above "W002" on Fig. 9, was the main decline to the underground workings on this mine while the adit that feeds the discharge sampled at W005 (Fig. 9) is considerably overgrown though still partly visible. A limited number of water samples were collected at Geevagh, including the adit discharge (W005) as well as a sample of water from a flooded open pit (W003) and a discharge from another open pit (W002) that flows into the excavated ground in front of McTiernan's Incline and appears to drain into the adit. As was done for other collieries, the waste heaps were included in the HMS-IRC Site Scoring system by employing data for the waste heap (SP01) at Derreenavoggy. Because there is no individual chemical data for each waste heap, instead of scoring each of the waste heaps separately all the heaps were aggregated together and labelled SP09. The total area and volume of solid waste were used to obtain a single score for solid waste heaps at Geevagh.

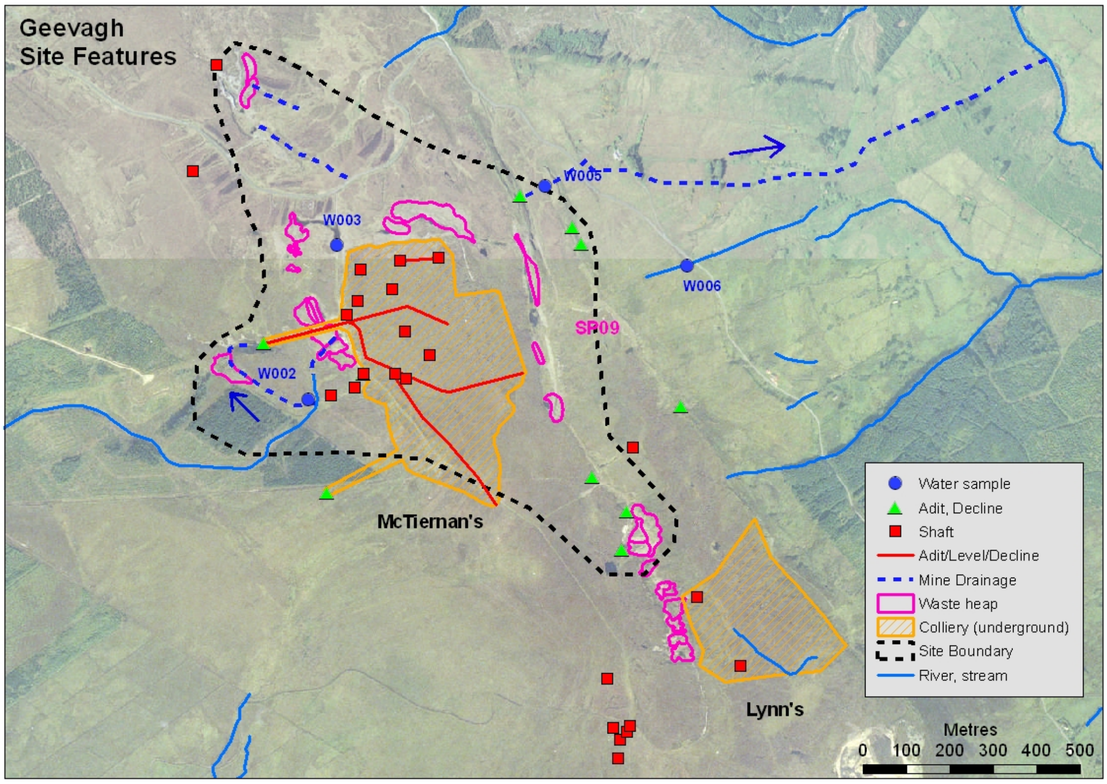

Fig. 9 Geevagh: mine features

6. Spion Kop

Mine Name: Spion Kop; Altagowlan

Counties: Roscommon, Leitrim

Townland: Altagowlan; Greaghnaglogh; Glackaundarragh; Seltanaskeagh; Seltanaveeny

Grid Reference: E191303, N319090

Spion Kop is the name used in this report to cover several collieries that were operated on Altagowlan – Spion Kop Mountain, the flat-topped ridge that lies north of and parallel to Kilronan. The site comprises a series of sub-sites distributed along the crest of the mountain just below the new windfarm which occupies the highest topographic point at its northwestern extremity. The area is remote, comprising heathland some commercial conifer plantations. Farms and houses are typically confined to the lower slopes of the mountain, spread out along the valley roads.

Mining at Spion Kop was more limited than that on Kilronan but was nevertheless extensive and at least seven individual collieries were worked by underground mining at various times (Fig. 10). Three of them, Tullynahaw, Seltanaskeagh and Seltanaveeny were operated in the 1890s with only the latter apparently surviving into the early 20th century. Spion Kop and Tullymurray were in operation in the 1940s when both closed down while Greaghnaglogh was worked from 1948 to 1963.

The most recent workings appear to have been those operated by Flynn and Lehany and Arigna Mines Ltd. at Glackanadarragh. There are several open pits in the area but some of these may be the consequence of sandstone quarrying. Recent earth movement in the course of the building of the adjacent windfarm has contributed to the volume of solid waste in the area.

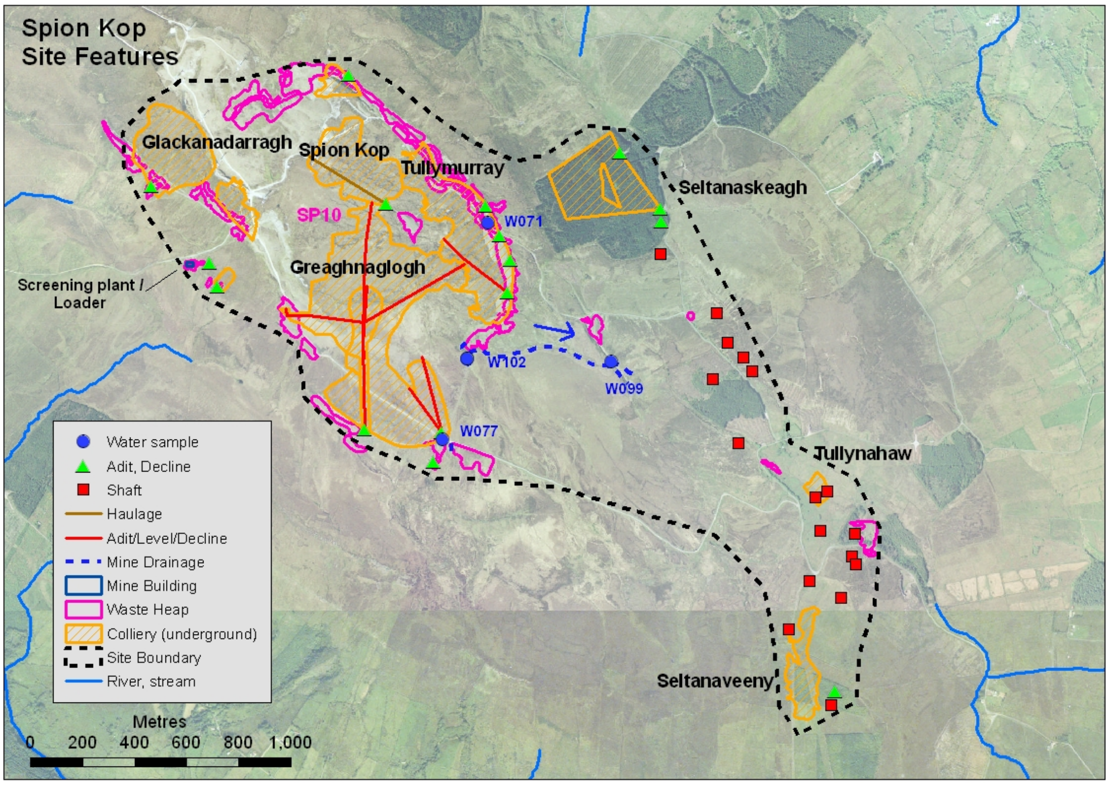

Fig. 10 Spion Kop: mine features

As is the case on other colliery sites in the Connacht Coalfield, most of the shafts and adits marked on the map are either backfilled or collapsed, leaving little or no trace. However, three adits in Tullymurray open pit are partly visible (photo, right) as is the adit that discharges mine water sampled at site W077. Only traces of other adits are preserved. Four water samples were collected at Spion Kop, including the adit discharge (W077) and standing water in and drainage from open pit excavations (W071, W099 and W102). As was done for other collieries in the district, the waste heaps were included in the HMS-IRC Site Scoring system by employing data for the waste heap (SP01) at Derreenavoggy. Because there is no individual chemical data for each waste heap, instead of scoring each of the waste heaps separately all the heaps were aggregated together and labelled SP10. The total area and volume of solid waste were used to obtain a single score for solid waste heaps at Spion Kop.

7. Bencroy

Mine Name: Bencroy

Alternative Name: Aghacashel (Wynne's)

County: Leitrim

Townland: Gubnaveagh

Grid Reference: E205202, N318898

Bencroy is east of Lough Allen on Sliabh an Iarainn, around 15km by road from Drumshanbo. The coal in this part of the coalfield has historically been poorly exploited, probably because of the remoteness of the area from towns and villages. Bencroy is on the eastern flank of the mountain, at a height of almost 500m, in an area of heathland. A small conifer plantation is the only sign of commercial activity in the vicinity of the site. Modern coal mining on the site appears to have begun around 1930 when Coll and Gannon began exploiting the 0.6m-thick Lower Crow Coal. Their operation was on the northern part of the site and the underground workings were reached via adits running northwest from the roadside (Fig. 11). Coll and Gannon continued operating for at least 15 years until 1946 when a screening plant, weighbridge and shelters were noted on the site by GSI (photo, left). At that time the company had started a drive 300m or so to the southwest. This would later be the site of the Aghacashel colliery, operated by the Wynne brothers in the 1980s. This colliery produced around 100-150 tons per week, almost all of it supplied to the ESB power station at Arigna.

Today there are substantial waste heaps on the steep mountain slopes above the adits (photo, above right) as well as the remains of an old opencast operation on the site of the Aghacashel colliery (photo, right), where coal was extracted from the outcropping seam. Coll's Adit (photo, below left) is the only accessible adit. It discharges a low flow of mine water (W109) except in summer months when it is typically dry. Water also discharges from an adit south of Coll's Adit and was sampled (W079) along with some other drainage of uncertain origin, possibly surface water (W083). As was done for other collieries in the district, the waste heaps were included in the HMS-IRC Site Scoring system by employing data for the waste heap (SP01) at Derreenavoggy. Because there is no individual chemical data for each waste heap, instead of scoring each of the waste heaps separately all the heaps were aggregated together and labelled SP11.

The total area and volume of solid waste were used to obtain a single score for solid waste heaps at Bencroy

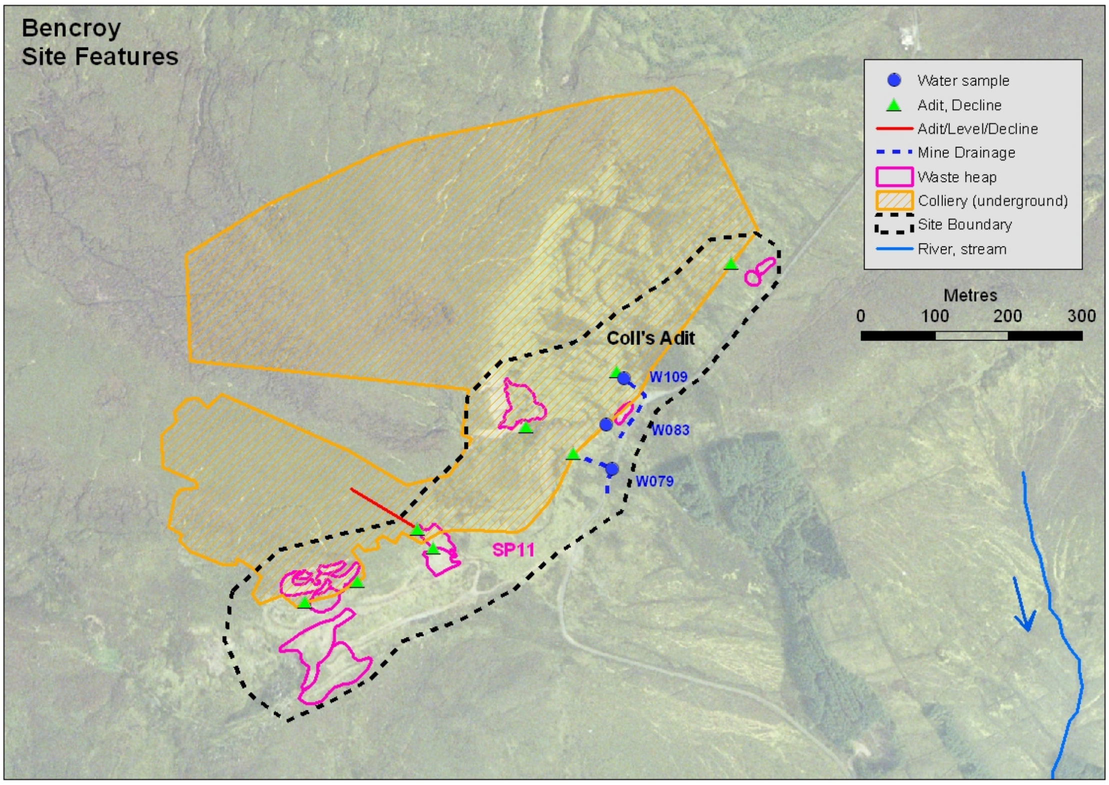

Fig. 11 Bencroy colliery: extant mine features

Geochemistry

Surface water, stream sediments and solid waste heaps in the Connacht Coalfield were analysed to identify possible environmental impacts related to mining. In addition, leachate tests were carried out on composite samples of solid waste.

1. Surface water and groundwater

Surface water and groundwater samples were collected in both winter (February 2007) and summer (August 2007). The surface water samples came from streams both upstream and downstream of mine sites, adit discharges, seepages and run-off from waste and, in one case, from an open pit lake. Samples of groundwater were taken from a natural spring.

In general, concentrations of potential contaminants were low in the Connacht Coalfield samples (Table 2). Significant variation was observed among some parameters, notably pH, conductivity (EC), Al, Ni and sulphate (SO_4) and these can be related to source type. Thus, adit discharges and seepages or run-off from solid waste heaps had relatively low pH, high acidity and high EC as well as significantly elevated concentrations of Al, Ni and SO_4. Table 2 summarizes the data for some of these parameters for all analyses carried during the project, both in winter and summer.

Table 2 Summary statistics for all water samples, Connacht Coalfield

	pH	EC	Al (tot)	Cd (tot)	Cu (tot)	Ni (tot)	Zn (tot)	SO_4
		mS/cm	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
n	53	53	53	53	53	53	53	53
Minimum	2.69	0.00	29	<1	7	<1	26	<3000
Maximum	8.21	1.09	14970	1	41	264	335	509000
Median	4.28	0.21	1184	<1	18	25	102	41000
Mean	4.82	0.31	3221	0.52	20	71	118	113349

The median concentrations for specific water sources are given in Table 3 where they can be compared to standard concentrations used for the HMS-IRC project. Most surface water samples from the Connacht Coalfield exceed the standard (drinking water) concentration for Al of 200 µg/l. Concentrations of Ni in mine water and in surface water downstream on mines are generally above standard limits while those for Zn routinely exceed standards limits in all sample types. Concentrations of SO_4 exceed standard limits only in adit discharges or in streams immediately downstream of them. Only six out of 53 samples had Cu concentrations in excess of the standard limit (30 µg/l where hardness exceeds 100 mg/l $CaCO_3$).

Table 3 Median concentrations, all water samples, by source, Connacht Coalfield

Medians	pH	EC	Al (tot)	Cd (tot)	Cu (tot)	Ni (tot)	Zn (tot)	SO_4
		mS/cm	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Upstream (n=4)	6.49	0.09	481	<1	16	11	78	19000
Downstream (18)	5.03	0.17	1184	<1	17	25	111	41000
Adit/Shaft discharge (18)	3.73	0.70	5693	<1	23	177	112	323000
Waste run-off (11)	3.63	0.30	2805	<1	22	52	111	88000
Open Pit Lake (2)	6.61	0.06	228	<1	13	4	44	4000
Well (3)	8.10	0.40	33	<1	13	3	34	21000
Standard value*	6.5-9.5	<2.5	200	0.25	5 - 30	20	8 - 100	250,000

***Standard value used for HMS-IRC. Values for Cu, Zn vary according to hardness of water**

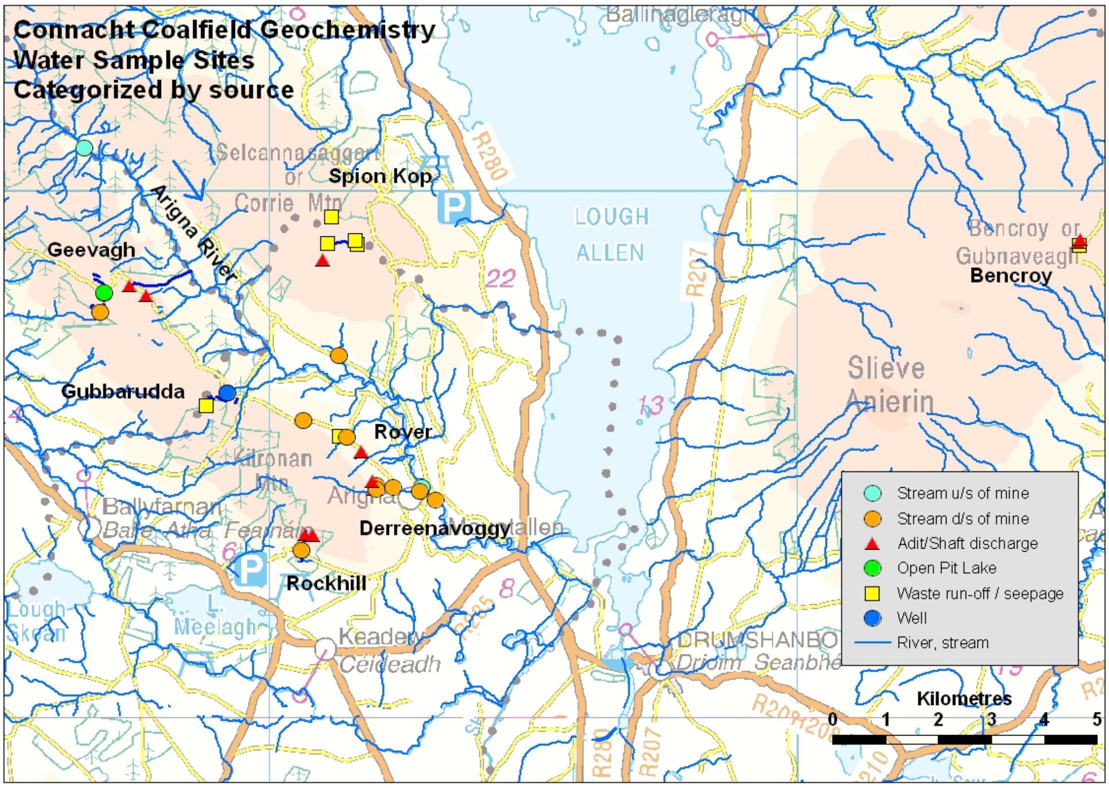

Fig. 12 Connacht Coalfield: water sampling sites

The highest acidity, EC and element concentrations and lowest pH were measured in adit discharges at Derreenavoggy and Rockhill, the latter where the adit discharge passed over spoil. At these sites, acidity exceeded 100 mg/l $CaCO_3$, pH ranged from 3.2 to 3.4 and EC from 0.7 to 1.1 mS/cm. In the coalfield as a whole, only adit discharges and surface run-off from waste heaps had pH below 4 but only the adit discharges at Rockhill and Derreenavoggy had acidity exceeding 100 mg/l $CaCO_3$. Relatively few samples of waste run-off were analysed but, as is the case for other coalfields, low pH, high EC and high metal concentrations should be expected in seepage and run-off from any solid waste heap that contains coal waste. Such waste can be expected to contain pyrite, either in macroscopic or microscopic form (McArdle 1992), with the potential to generate water with low pH, high acidity and high metal concentrations. The elevated concentration of sulphate (SO_4) in seepage and run-off samples (4,000 – 192,000 µg/l) is a direct indication of the presence of pyrite in the waste.

Among the various parameters measured for the HMS-IRC project, sulphate is possibly the most useful for demonstrating the impact of mine sites on water in the Connacht Coalfield because it is widely present in samples analysed and can be directly linked to coal waste. Fig. 13 shows the range in sulphate concentration as a function of water source for all samples analysed, collected in both winter and summer. In this case, adit discharges, seepages and run-off from waste heaps and open pit lake waters have been bundled together as "mine water". It is clear from Fig. 13 that water in streams downstream of mines do show consistently higher concentrations of SO_4 than those upstream of sites.

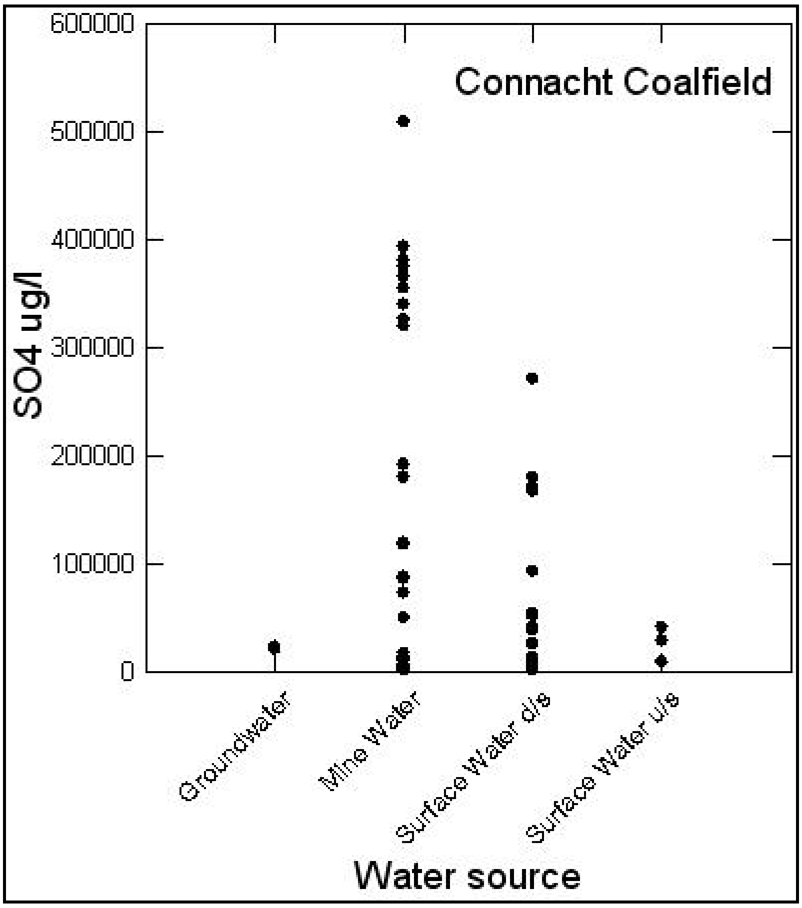

Fig. 13 SO_4 by water source, Connacht Coalfield

Apart from metal contamination, the most important chemical issue related to mine water discharges from coal mines worldwide is acid mine drainage (AMD) or acid rock drainage (ARD), generated as a consequence of reaction between mine water and sulphides, mainly pyrite, in the coal and its host rock. Water with high acidity generally has low pH but low-pH waters do not necessarily have high acidity. Most water analysed in the Connacht Coalfield had pH less than 7.0 but the measured acidity is generally low. This reflects the general absence of significant concentrations of ions, e.g. metals, in the water. As discussed above, only adit discharge samples from Derreenavoggy and one sample from Rockhill had low pH and relatively high (. 100 mg/l $CaCO_3$) acidity. The general relationship between pH and acidity for all samples collected in the district is shown in Fig. 14. As is the case for the Slieve Ardagh and Leinster coalfields, although low-pH, high-acidity samples can be generated under specific circumstances and in specific locations, acidity is generally not a significant factor in the Connacht Coalfield and the risk of AMD therefore appears to be low.

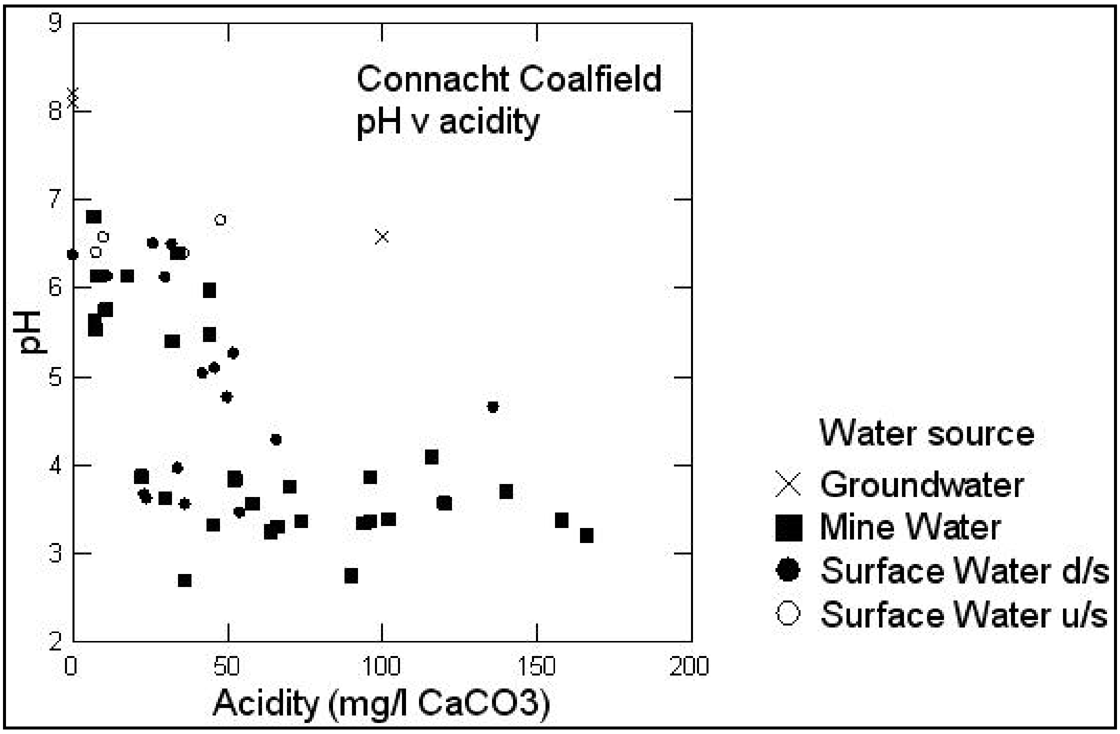

Fig. 14 pH v Acidity, Connacht Coalfield

The groundwater samples taken from a spring and associated well in Gubbarudda had very low metal concentrations as well as high pH and low conductivity (Table 3). Unfortunately, no leachate samples were prepared from Connacht Coalfield solid waste. Analysis of samples of ponded water and run-off from solid waste suggest that leachate from solid waste heaps in the district is likely to be relatively enriched in metals and have low pH and relatively high acidity. However, the concentrations of metals measured in Connacht Coalfield run-off are lower than those measured for solid waste in the other coalfields, possibly reflecting a somewhat lower proportion of coal in the waste heaps.

2. Stream Sediments

Stream sediments were collected at six sites in the district, four along the Arigna River, one in the stream that drains Derreenavoggy and flows into the Arigna River and the other one in a stream at the foot of Spion Kop (Fig. 15). The samples along the Arigna River include one upstream of all coal mining operations (SS001) and three that are downstream of various mines (Fig. 15). The Derreenavoggy stream is fed by at least two adit discharges at Derreenavoggy and flows into the Arigna River. Samples SS003 and SS004 were taken in the Arigna River upstream and downstream, respectively, of the confluence with the Derreenavoggy stream. Sample SS008 was taken a further 400m downstream from SS004. Sample SS002 was taken from the Derreenavoggy stream, downstream of the mine site. Table 4 summarizes the results for the samples collected.

In general, concentrations of metals in stream sediments collected around mine sites in the Connacht Coalfield are very low, generally much lower than the metal sediment limit concentrations for livestock exposure adopted for the HMS-IRC project, with the exception of Fe (Table 4). The small number of samples taken allows only very tentative conclusions but there is no evidence to suggest that mining has had any significant impact on stream sediment composition. Elements that are somewhat enriched in mine water, such as Ni and Zn, do not show significant enrichment in the stream sediment samples analysed. Fe concentrations do consistently breach the 10,000 mg/kg limit for livestock exposure but downstream samples are not notably enriched relative to the upstream sample.

Table 4 Summary statistics for stream sediment analyses, Connacht Coalfield

mg/kg	As	Pb	Zn	Cu	Ni	Fe	Mn
SS001 (Arigna R, u/s)	19	30	57	36	59	74,858	2258
SS003 (Arigna R, u/s)	16	37	85	49	85	68,440	2510
SS004 (Arigna R, d/s)	16	30	68	44	71	83,245	2508
SS008 (Arigna R, d/s)	22	34	85	47	0.0	120,793	2827
SS002 (Derreenavoggy, d/s)	11	26	90	42	62	31,156	1670
SS007 (Spion Kop, d/s)	13	27	0.0	39	0.0	86,862	1467
Limit concentrations	300	1,000	5,000	100	1,000	10,000	5,000

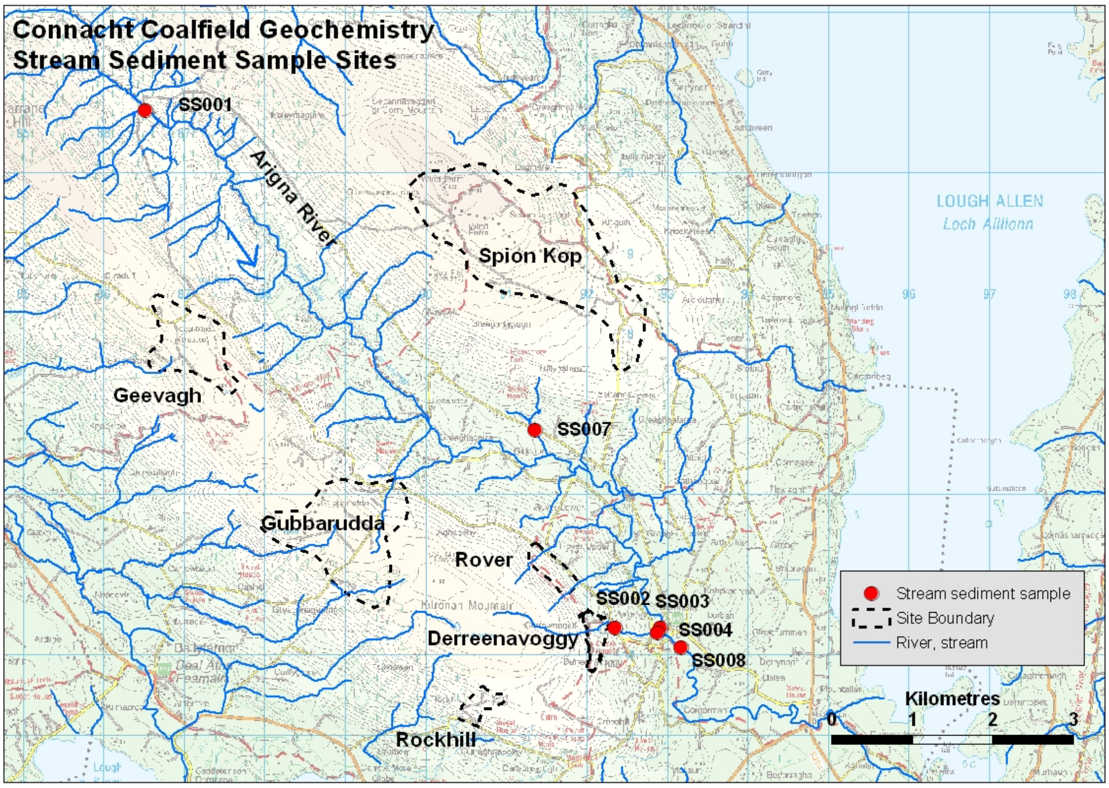

Fig. 15 Stream sediment sampling sites, Connacht Coalfield

3. Solid waste

There are many extant waste heaps in the Connacht Coalfield. Most consist of sandstone and shale with a small amount of coal waste and their potential to contain significant concentrations of contaminants such as metals are low. The main waste heap at Derreenavoggy (SP01), one of the most coal-rich in the district, was selected for *in-situ* XRF analysis. The results for this heap were applied to all waste heaps in the district when computing a score for each heap under the HMS-IRC Site Scoring system.

Analysis of the waste at Derreenavoggy indicates that it contains very low concentrations of metals (Table 5). Compared to regional median data from the National Soils Database (www.epa.ie/nsdb), computed using six soil samples from sites overlying the Namurian bedrock in the Connacht Coalfield area, the waste at Derreenavoggy cannot be considered to be enriched in metals. Indeed, it may even be depleted in Zn and Ni (not detected in any sample) and Cu (Table 5). The measured concentrations of other elements such as As and Pb are very modest, if slightly above the regional median for soils.

As is the case in the Leinster Coalfield, Ni was below the detection limit in all solid waste analyses, despite its relatively high concentration in some water analyses. This may reflect high detection limits in the XRF. Arsenic, detected in most solid waste samples, was detected in very few water analyses despite the reduced-pH conditions that would be expected to increase its solubility.

Table 5 Summary statistics for solid waste analyses, Slieve Ardagh

mg/kg	As	Pb	Zn	Cu	Ni
All analyses					
n	7	7	7	7	7
Minimum	0.0	26	0.0	0.0	0.0
Maximum	24	42	0.0	38	0.0
Median	22	38	0.0	0.0	0.0
Mean	19	35	0.0	10	0.0
***NSDB* (median)**					
Namurian (n=6)	4	21	22	4	4

The median concentrations for elements analysed in solid waste at Derreenavoggy have been applied to remaining waste heaps in the district in order to score them for the HMS-IRC Site Scoring system. There are numerous such waste heaps in the district, consisting mainly of shale and sandstone with subordinate amounts of coal waste. Many are grassed over or otherwise overgrown by vegetation but they have been included where volume estimates are available. For the purpose of the HMS-IRC project and with the exception of Derreenavoggy, the area and volume of all waste heaps in any one site were amalgamated and the total area and volume used to score the waste at the site. Table 6 below lists the amalgamated solid waste heaps and their area and volume estimates.

Table 6 Solid waste heaps, Leinster Coalfield

Waste ID	Site	Area (m^2)	Volume (m^3)
SLA-SP01	Derreenavoggy	15,655	326,647
SLA-SP02	Derreenavoggy	1,975	11,129
SLA-SP03	Derreenavoggy	360	504
SLA-SP04	Derreenavoggy	203	1,320
SLA-SP05	Derreenavoggy	1,693	7,618
SLA-SP06	Rover	16,745	175,553
SLA-SP07	Rockhill	21,453	50,319
SLA-SP08	Gubbarudda	49,640	207,663
SLA-SP9	Geevagh	41,978	135,134
SLA-SP10	Spion Kop	156,067	1,026,127
SLA-SP11	Bencroy	18,480	57,110

4. HMS-IRC Site Scores

Table 7 Site Scores for mine waste, Connacht Coalfield

Waste	SP01	SP02	SP03	SP04	SP05	SP06
1. Hazard Score	19	11	10	10	10	15
2. Pathway Score						
Groundwater	1.38	0.75	0.65	0.65	0.66	1.13
Surface Water	5.02	1.28	3.30	3.32	1.86	2.82
Air	0.01	0.00	0.00	0.00	0.00	0.00
Direct Contact	0.20	0.01	0.00	0.00	0.01	0.08
Direct Contact (livestock)						
3. Site Score	**7**	**2**	**4**	**4**	**3**	**4**

Waste	SP07	SP08	SP09	SP10	SP11	W028
1. Hazard Score	12	16	14	39	12	31
2. Pathway Score						
Groundwater	0.72	1.44	1.28	2.07	0.27	1.24
Surface Water	2.37	0.10	2.59	7.46	0.19	7.86
Air	0.00	0.00	0.00	0.02	0.00	
Direct Contact	0.08	0.13	0.13	0.77	0.03	
Direct Contact (livestock)						
3. Site Score	**3**	**2**	**4**	**10**	**0**	**9**

Waste	W064	W068	W077	W109	Sseds	Total
1. Hazard Score	34	18	84	7	0	342
2. Pathway Score						
Groundwater	1.31	0.84	4.42	0.04		18.84
Surface Water	10.48	2.41	19.15	0.08		70.29
Air						0.05
Direct Contact						1.45
Direct Contact (livestock)					0	
3. Site Score	**12**	**3**	**24**	**0**	**0**	**91**

Table 7 gives the HMS-IRC site scores for each individual waste source in the Connacht Coalfield that has been scored. The total score for the district is 91, of which solid waste accounts for 47% (43) and adit discharges 53% (48). Stream sediments make no contribution to the total score since they are not contaminated by any mine-related element. The low metal concentrations in solid waste in the area account for the relatively low contribution it makes to the total score, given the high volume of material in the district (Table 6). Conversely, adit discharges have elevated metal contents, notably Al, Ni and Zn, and these account for the relatively high contribution they make to the total score despite the relatively low volumes of water recorded in the five adits included in the scoring (Table 7).

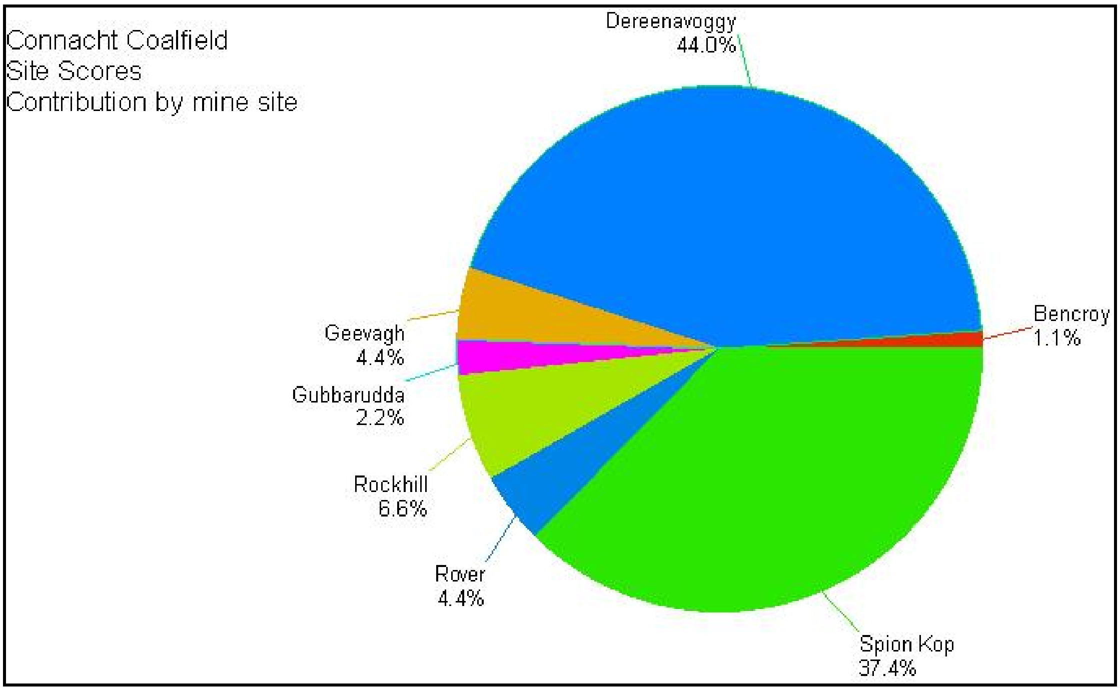

Fig. 16 Connacht Coalfield, site scores, contribution by mine site

Fig. 16 shows the contributions to the total site score by individual mine sites in the district. Derreenavoggy (40 or 44% of the total) and Spion Kop (34 or 37.4%) dominate because of the volume of solid waste on these sites and the presence of adit discharges in both. The only other site with a significant adit discharge is Rockhill and it has the third highest score (6 or 6.6%).

Fig. 17 shows the contribution to the total site score by individual pathways. The proximity of streams to most sites boosts the surface pathway score but this is balanced by the groundwater vulnerability ("extreme" aquifer vulnerability in most cases, according to GSI's classification). The relatively small contribution by the direct contact and air pathways reflects the very low concentrations of elements of interest in the solid waste.

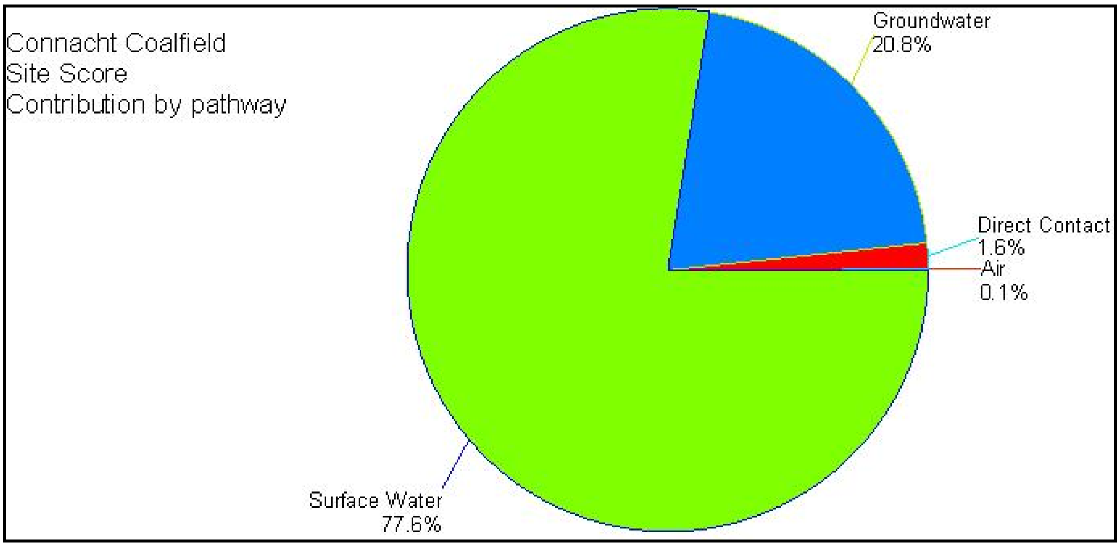

Fig. 17 Connacht Coalfield, site scores, contribution by pathway

5. Geochemical Overview and conclusions

The Connacht Coalfield district is a very extensive area with numerous abandoned mine operations. It occupies the area east and west of Lough Allen, upland which is drained by a network of streams exposed to potential impacts from coal mining. Few of the mine sites have been rehabilitated since closure though natural revegetation has reclaimed significant portions of the sites. Large waste heaps, open pit lakes and active drainage adits remain and are the main potential sources of environmental impacts in the district.

Water draining from mine adits in the district has relatively high concentrations of elements such as Al, Ni, Zn and SO_4 as well as low pH and high EC and acidity. Stream water downstream of such discharges also displays elevated concentrations of some of these elements, notably Ni and SO_4. Water ponded upon or running off solid waste heaps shows similar chemical patterns although the concentrations of metals tend to be lower than in adit discharges. Concentrations of Ni in mine water and in surface water downstream on mines are generally above standard limits while those for Zn routinely exceed standards limits in all sample types. Concentrations of SO_4 exceed standard limits only in adit discharges or in streams immediately downstream of them. Most surface water samples from the Connacht Coalfield exceed the standard (drinking water) concentration for Al of 200 µg/l. Samples of stream water taken further downstream of mine sites and adit discharges show only very limited and localized chemical impact from mining.

Solid waste analysis at one site revealed no significantly elevated metal concentrations. The absolute concentrations measured were low and unlikely to have any negative implications for human or animal health. Analyses of stream sediments showed no obvious impact from mining and metal concentrations were below guideline limits for the protection of livestock. The total HMS-IRC Site Score for the Connacht Coalfield is 91, placing it in Class V.

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