Gold potential of the Dalradian rocks of north-west Northern Ireland: prospectivity analysis using Tellus data

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ABSTRACT

The Dalradian terrane in the north-west of Northern Ireland is prospective for orogenic vein-hosted gold mineralisation with important deposits at Curraghinalt and Cavanacaw. New geochemical and geophysical data from the DETI-funded Tellus project have been used, in conjunction with other spatial geoscience datasets, to map the distribution of prospectivity for this style of mineralisation over this terrane. A knowledge-based fuzzy logic modelling methodology using Arc Spatial Data Modeller was utilised.

Four main groups of targets were identified, many close to known occurrences in the Lack-Curraghinalt zone and others in prospective areas identified by previous investigations. Additional targets are located along west-north-west trending linear zones at the southern edge of the Newtownstewart Basin and to the north of the Omagh-Kesh Basin. These zones may be related to major structures linked to a westward extension of the Curraghinalt lateral ramp which is regarded as an important control on the location of the Curraghinalt deposit.

Keywords: orogenic gold, prospectivity analysis, Dalradian, Northern Ireland

INTRODUCTION

Northern Ireland has a long history of mineral production and its diverse geology is prospective for a range of mineral deposit styles. Historical production largely focused on iron ore, coal, lead and salt, with in excess of 2000 abandoned mine workings.[4] The occurrence of gold in Northern Ireland was originally documented in the mid-1600s with the discovery of alluvial grains in County Londonderry.[10,19] The first modern gold exploration in Northern Ireland was undertaken in the early 1980s in response to rising gold prices, interest in historical records of gold occurrences and a review of the mineral potential of the Sperrin Mountains area conducted by the Geological Survey of Northern Ireland (GSNI).[3] Exploration primarily focused on determining bedrock sources of alluvial gold in the Sperrin Mountains and successfully identified extensive shear zones with associated vein gold mineralisation in bedrock, indicative of a 'gold mineral province'.[19] The most significant discoveries were Curraghinalt and Cavanacaw, now the operating Omagh Mine.[11,17,18,24,25] Elsewhere Caledonian basement rocks north of the Iapetus suture in the British Isles also contain significant gold mineralisation, from the Mayo-Curlew Basin of western Ireland (Cregganbaun and Croagh Patrick)[56,58] through the North Western Basement and Longford Down Massif (Curraghinalt, Cavanacaw and Clontibret)[16,45,52] and into Scotland (Cononish, Calliacher-Urlar Burn, Glenhead etc).[22,38]

Rising commodity prices in recent years have generated considerable interest in the mineral potential of Northern Ireland. In addition a wealth of new geological, geochemical and geophysical data from the Tellus Project (2004–07) has provided new insights into the geology of Northern Ireland and indicated potential for the discovery of new deposits in several areas. The present study aimed to assess the potential for shear zone associated vein-hosted gold mineralisation in north-west Northern Ireland using Geographic Information System (GIS)-based prospectivity analysis. The study area (3074 km^2) includes the main tract of Dalradian rocks in north-west Northern Ireland and was selected because of its prospective geology and known gold occurrences, including the major gold deposits of Curraghinalt and Cavanacaw (Fig. 1). The study integrates the new Tellus geophysical and geochemical data, legacy datasets and regional geological mapping within a framework provided by the latest mineral deposit models for vein-hosted gold mineralisation in Northern Ireland.

GEOLOGY

For its limited size (some 14 000 km^2), Northern Ireland hosts a remarkable variety of geology with rock representatives from the Mesoproterozoic through to the Palaeogene. These rocks contain evidence of major plate-tectonic events including the Palaeozoic Grampian and Caledonian orogenies, the late Palaeozoic Variscan Orogeny and the ongoing Alpine Orogeny. Northern Ireland straddles the Southern Uplands-Down-Longford, the Midland Valley and the Central Highlands (Grampian), pre-late Palaeozoic basement terranes.[9] The boundaries between these are the major, long-lived, Southern Uplands and Highland Boundary fault zones. The latter is well defined in Scotland, but less so in Northern Ireland where it is concealed by Devonian and younger cover sequences and the Omagh Thrust.

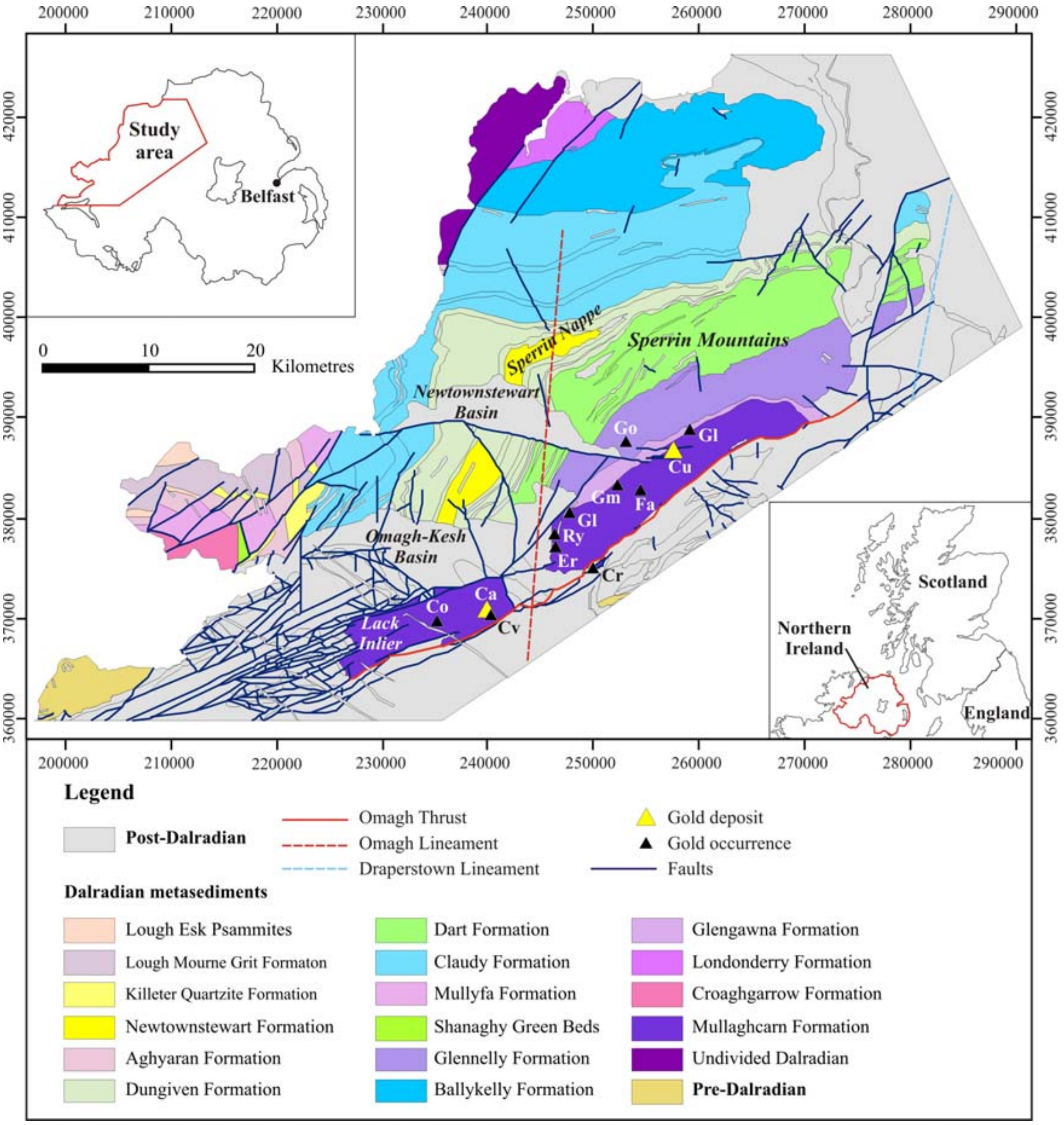

Fig. 1 Geology of the study area showing the Dalradian formations, pre- and post-Dalradian geology[27], principal structural features and mineral occurrences (Cu, Curraghinalt; Cv, Cavanacaw; Co, Cornavarrow; Cv, Creevan Burn; Er, Erganagh Burn; Ry, Rylagh Burn; Gl, Glengawna; Gm, Glenmacoffer; Fa, Fallagh; Go, Golan Burn; Gl, Glenlark; Cr, Crosh). © Crown copyright

The prospectivity analysis focused on the Dalradian Supergroup in the Sperrin Mountains which is located in the Central Highlands Terrane and is part of the Caledonian orogenic belt extending into western Ireland and Scotland and further afield into Newfoundland and Scandinavia. The Dalradian Supergroup was formed as a consequence of the late Neoproterozoic break-up of the supercontinent of Rodinia and the opening of the Iapetus Ocean.[51] Deposition took place along the eastern side of Laurentia where extensive passive margin sedimentary sequences were formed in response to continental rifting and ocean widening, lasting until the early Ordovician.[54] The predominantly siliciclastic Dalradian sequences preserved in Scotland and Ireland record shallow to deep-water depositional environments with intercalated, subordinate lithologies related to periods of glaciation, carbonate deposition and basic volcanism.

The regional structure and stratigraphy of the Dalradian Supergroup in the Sperrin Mountains has been the subject of longstanding debate. Based on GSNI mapping, the preferred structural interpretation is a broad anticline referred to as the Sperrin Nappe, which is considered analogous to the Tay Nappe in Scotland.[27,54] The Sperrin Nappe is south-east facing and composed mainly of Southern Highland Group formations disposed either side of an axis that runs within upper Argyll Group stratigraphy. An alternative model involves a greater proportion of Argyll Group stratigraphy forming the main Sperrin ridge, with a main axis located further south than proposed by GSNI.[53] The structure and stratigraphy of the Sperrin Mountains revealed by recent mapping of the Dungiven, Newtownstewartand Strabane 1:50 000 scale sheets is more consistent with the interpretation of Alsop and Hutton[1], but appears to be far more structurally complicated than previously thought.[28–30] From north-west to south-east, a succession of folds and thrust surfaces is identified that repeats a relatively thin portion of upper Argyll Group and lower Southern Highland Group stratigraphy.

The lower Ordovician Tyrone Igneous Complex (TIC) crops out to the south-west of the Omagh thrust and comprises the ophiolitic Tyrone Plutonic Group and overlying arc-related Tyrone Volcanic Group.[21,36] Together they structurally overlie sillimanite-grade paragneisses of the Tyrone Central Inlier which, based on detrital zircon age profiling, appear to be of Upper Dalradian Laurentian affinity. The obduction of the ophiolite appears to have taken place at c. 475 Ma followed by the establishment of northward-directed subduction and the formation of a volcanic arc by c. 470 Ma.[14] The thrusting of the Dalradian over the TIC is believed to have occurred c. 465 Ma during Grampian orogenesis.

Two major north–south-trending, pre-Dalradian basement features, the Omagh Lineament and Draperstown Lineament have been recognised within the study area. Similar structures have been identified in the Dalradian of north-west Donegal and south-west Scotland because of their influence on Dalradian sedimentation patterns and regional strike orientation.[37] The Omagh Lineament is thought to be responsible for a major change in the orientation of bedding and of the dominant foliation in Dalradian rocks at the eastern end of the Lack Inlier.[26]

PROSPECTIVITY ANALYSIS

A mineral deposit model describes the essential attributes of a mineral deposit class, based on the synthesis of large quantities of data derived from similar deposits worldwide. Key exploration criteria for a particular deposit class can be identified from the mineral deposit model, thus forming a basis for assessing mineral potential of a region.

It has long been recognised that integration of multiple geoscience datasets is advantageous for mineral exploration targeting. Geographical Information Systems (GIS) are now routinely used for the management, manipulation, processing and integration of voluminous spatial exploration datasets. Examination of multiple datasets in the GIS environment can aid the determination of features critical or incidental to the mineralisation process and emphasise patterns and associations that may not be obvious when the datasets are viewed in isolation. Prospectivity analysis is a GIS-based predictive spatial analysis technique used to integrate multiple exploration datasets in the framework of a mineral deposit model. The output of the process is a map displaying favourability for the occurrence of a particular mineral deposit type.[2]

Spatial data modelling methodologies used in prospectivity analysis can be divided into two categories: knowledge-driven techniques, including Boolean logic, index overlay, and fuzzy logic; and data-driven techniques, such as weights of evidence (WoE), logistic regression and neural networks.[12]

Data-driven techniques, which were not utilised in this study, require a set of known mineral occurrences or 'training points'. In this approach the data relationships at known occurrences are analysed to determine a 'fingerprint' of the target mineralisation and the weights allocated to different evidential themes are derived statistically.[57]

Knowledge-driven analysis is conducted by an 'expert' who identifies those criteria in the mineral deposit model that are critical to the formation of a deposit. The formation of a mineral deposit is likely to depend on the spatial and temporal coincidence of multiple controlling features. It is necessary to determine which of these characteristic features can be identified in the exploration data to develop an exploration model. Frequently only part of the mineral deposit model can be mapped with the data available and the exploration model defines which evidential data layers are used in the prospectivity analysis. Knowledge-driven analysis is generally employed in regions with few or no known mineral occurrences. Knowledge-driven techniques are subjective in that they rely on expert opinion to determine weightings which rank the relative significance of the exploration criteria.

Knowledge-driven prospectivity analysis using fuzzy logic was employed in this study. In classical set theory an object is either a member of a set (membership = 1) or not a member (membership = 0), there is no intermediate state.[2] In contrast the fuzzy logic method, based on fuzzy-set theory devised by Zadeh[61], allows assignment of weightings to exploration criteria on a continuous scale from 1 (full membership) to 0 (full non-membership).[2,12] Once fuzzy membership values have been assigned to evidential data layers they can be combined using certain mathematical operators to produce a map of mineral potential.

The fuzzy logic methodology has been applied to exploration for orogenic gold deposits in a number of areas including the Yilgarn Block of Western Australia,[32,40] the Lynn Lake Greenstone Belt of Canada and the northern Fennoscandian Shield of Finland.[43,49] In the UK prospectivity analysis has been employed to determine favourable areas for lode gold mineralisation in the Scottish Dalradian,[34] turbidite-hosted gold deposits in the Lower Paleozoic Welsh Basin,[20] epithermal gold mineralisation in the Devonian rocks of northern Britain[35] and stratiform massive sulphide mineralisation in south-west England.[7]

This study utilised the free internet downloadable Spatial Data Modeller extension (Arc-SDM, version 3.1),[50] with ESRI's ArcGIS software described by Raines and Bonham-Carter[47], making use of ESRI's Spatial Analysis extension for much of the data pre-processing.

MINERAL DEPOSIT MODELS AND KEY EXPLORATION CRITERIA

Orogenic vein-hosted gold mineralisation

Gold mineralisation is widely developed throughout the Caledonian orogenic belt, from Scandinavia in the north to the south-eastern USA in the south. Goldfarb *et al.*[31] identified gold deposits associated with the Caledonian Orogeny in the British Isles as examples of

Palaeozoic orogenic gold mineralisation. It is generally accepted that orogenic gold mineralisation is associated with low salinity (typically in the range of 3–7 wt. % eq. NaCl), mixed aqueous-carbonic fluids, transporting gold as reduced sulphur complexes, derived from either metamorphic devolatilisation or a deep magmatic source. Mineralising conditions generally fall in the range of 1.0–2.5 kbars at 300–350^{o}C.[48] Orogenic gold deposits are typified by quartz-carbonate-dominant vein systems associated with deformed metamorphic terranes of all ages. Mineralisation displays strong structural controls at a variety of scales. Deposits are most commonly located on second- or third-order structures in the vicinity of large-scale compressional or transpressional structures formed at convergent margins (Table 1).[33]

Criteria	**Identified in project area**
Collisional tectonic regime	Yes
Major accretionary boundary structures	Yes
‘First-order’ transcrustal structures	Yes
High angle ‘second-order faults’ related to major structures	Yes
Rocks of greenschist metamorphic grade	Yes
Mineralisation is post-peak metamorphism (i.e. late syncollisional)	Yes
Late syncollisional, intermediate to felsic magmatism	Yes
Tabular veins in more competent lithologies with veinlets and stringers forming stockworks in less competent units	Yes
Ore mineralogy: gold, pyrite, arsenopyrite, native gold, Cu, Pb, Zn and Sb sulphides	Yes
Gangue mineralogy dominated by quartz ± carbonate, feldspar, mica	Yes
Wall-rock alteration	Yes
Elevated values of Au, Ag, As, Sb, K, Li, Bi, W, Te, Cu, Pb, Zn, Cd in rock, soil and stream-sediment	Selected elements (see text for discussion)
C-O-H ± N, near-neutral to low pH, low salinity fluids	Yes

Table 1 Characteristics of Phanerozoic orogenic vein gold mineralisation and their occurrence in the study area (criteria compiled from: Bierlein and Crowe[8]; Ash *et al.*[5]; Nesbitt[42]; Earls *et al.*[26]).

Vein-hosted gold mineralisation in Northern Ireland

Various recent publications have greatly advanced the understanding of gold mineralisation in the Sperrin Mountains of Northern Ireland e.g. Earls *et al.*[26], Wilkinson *et al.*[59], Parnell *et al.*[45]. The majority of research has focused on the deposits at Curraghinalt and Cavanacaw from which the prospectivity models used in this study have been generated. The following summary is derived chiefly from Earls *et al.*[26].

Structure appears to be the most significant factor controlling the distribution of auriferous gold veins in the Sperrin Mountains. Earls *et al.*[26] suggest that the interplay of three principal geological structures influences the location of gold mineralisation (Fig. 1):

1. The north-north-east-trending Omagh Lineament. Based on the distribution of gold and arsenic anomalies and the north-north-east to north–south orientation of mineralised veins in the vicinity of the Lack Inlier, Earls *et al.*[26] conclude that the Omagh Lineament has a significant control on the location and orientation of mineralised veins.
2. The north-east-trending Omagh Thrust which demarcates the southern boundary of the ‘Lack – Curraghinalt zone’ and separates the Dalradian from the underlying TIC. During the early to mid Ordovician the Dalradian was thrust over the volcanic rocks of the TIC along this zone of south-east directed thrusting. Subsequent reactivation during the

Variscan (c. 300 Ma) resulted in thrusting of the Dalradian over Carboniferous and Devonian rocks in addition to the TIC.[26]

3. The west-north-west-trending, north-dipping Curraghinalt Lateral Ramp. This positive relief structure developed within the TIC in the footwall of the Omagh Thrust, resulted in a regime of north-west-directed extension and the formation of east–west orientated accommodation structures.[26]

The principal exploration targets for gold mineralisation in the Sperrin Mountains are Dalradian metasedimentary rocks (Table 2). Arthurs[3] indicates that "the main (Dalradian) prospecting targets are within the …. Glengawna Formation and the Dungiven Formation". In addition, Lower Carboniferous and other post-Dalradian lithologies have also been considered prospective for gold mineralisation, following the proposal by Wilkinson *et al.*[59] that pre-existing Caledonian gold mineralisation may have been remobilised by later low-temperature brines.

In general, mineralised veins are preferentially developed in relatively brittle psammitic units in contrast to the more ductile pelites.[19,26] It is therefore suggested that particular Dalradian formations are more prospective for gold mineralisation based on their favourable rheological properties and the distribution of known occurrences (Table 2). Earls *et al.*[26] indicate an apparent association between gold mineralisation and graphitic pelite horizons of the Glengawna Formation. This association may be attributed to the rheological contrast between the graphitic pelites and associated lithologies and/or the presence of a reducing environment promoting gold deposition associated with the graphitic pelites.

Formation name	**Rank**
Glengawna Formation	10
Mullaghcarn Formation	8
Dungiven Formation (Carbonates)	6
Dungiven Formation (Non-carbonate)	5
Glenelly Formation	5
Dart Formation	5
Newtownstewart Formation	5
Londonderry Formation	3
Ballykelly Formation	5

Table 2 Relative ranking of principal Dalradian formations in the Sperrins based on their favourability for hosting gold mineralisation (10 = highest favourability)

Quartz is the dominant gangue mineral associated with the gold mineralisation but several carbonate phases, including calcite, dolomite and siderite, also occur. Multiple stages of quartz deposition and a range of sulphide minerals, including pyrite, arsenopyrite, chalcopyrite, galena and sphalerite, are recognised in the auriferous veins throughout the Sperrins.[26,45] Earls *et al.*[26] report that wallrock alteration at Curraghinalt is limited but potassic and argillic alteration are commonly associated with the veins at other localities.

Curraghinalt

The Curraghinalt deposit consists of a series of west-north-west-trending, north-east-dipping gold-bearing quartz veins, related to east–west-trending vertical and north-dipping shear zones. The auriferous veins are cut by low angle, north-dipping thrust faults and north-east-trending normal faults.[19,26,45] Structural evidence suggests that Curraghinalt overlies a lateral ramp structure. Earls *et al.*[26] propose a model whereby space was created by predominantly east-south-east-directed thrusting over the footwall ramp, resulting in the formation of east–west orientated accommodation structures. Minor changes in thrusting direction relative to the strike of the ramp resulted in both contractional and extensional deformation of the hanging wall Dalradian rocks creating space in the system.[26] The veins bifurcate, pinch and swell along strike in a host sequence of pelites, semipelites and psammites, varying in width from a few millimetres up to 3 m.[4,19] Curraghinalt is located within rocks of the Dalradian Mullaghcarn Formation.

Cavanacaw

The Cavanacaw deposit, discovered in 1985, is located in the eastern part of the Lack Inlier which is mapped by the GSNI as entirely Mullaghcarn Formation (Fig. 1).[27] However, lithological descriptions from the deposit suggest it may be hosted in both the Mullaghcarn and Glengawna Formations.[26] The largest mineralised structure at Cavanacaw, the Kearney vein, strikes north–south, whilst an additional set of veins strikes south-east. An east-north-east-striking fracture system known locally as the 'Lack Shear' displaces both vein sets.[16]

Other vein-hosted gold occurrences

In addition to Curraghinalt and Cavanacaw other notable mineralised localities in the district include (Fig. 1):

- Golan Burn, approximately 4 km west-north-west of Curraghinalt, which may represent the north-west strike extension of the Curraghinalt mineralisation;[4]
- Glenlark Lodge 5 km north-north-east of Curraghinalt, which consists of quartz vein and stratiform sulphide mineralisation;
- Rylagh Burn and Erganagh Burn, north-east of Cavanacaw, which comprise north–south-trending, shear zone-associated auriferous quartz veins;
- Creeven Burn, to the south of Cavanacaw, where mineralisation is associated with the 'Lack Shear' and graphitic pelites;
- Cornavarrow, west of Creevan Burn, also within the 'Lack Shear', where auriferous quartz veins are hosted in low-angle faults in graphitic pelites and psammites.[26]

Deposit-scale variations

Structure

Although the Curraghinalt and Cavanacaw deposits have many common features, significant differences are observed at the local scale, in the principal structural controls, mineralogy and geochemical signatures. As a result two separate prospectivity models, referred to as the Curraghinalt and Cavanacaw models, were utilised in this study.

The north-east-trending Omagh Thrust and the inferred north–south-trending basement lineaments are considered prospective in both models due their regional influence as zones of fluid flow and structural control. The deposits at Curraghinalt and Cavanacaw both lie in close proximity to these structures. The Omagh Thrust is directly linked to space creation in the vicinity of Curraghinalt and is accordingly given greater weighting in the Curraghinalt model. Greater significance is assigned to the basement lineaments and north–south-trending faults in the Cavanacaw model as the Omagh Lineament is thought to have allowed the Dalradian to accommodate north–south-trending veins and extensional shear zones such as those which occur at Cavanacaw and Rylagh Burn.[26]

North-east-trending structures are considered prospective in both models, reflecting the importance and orientation of the Omagh Thrust and related parallel structures. This trend also corresponds to the orientation of the normal faults cutting the veins at Curraghinalt. This orientation has greater significance in the Curraghinalt model due to the close association between the north-east-trending Omagh Thrust and space creation in the deposit.

East- to east-south-east-trending structures are considered highly prospective in the Curraghinalt model on the basis of the orientation of the Curraghinalt vein swarm (east-south-east) which appears related to east-west-trending shear zones.[26] The Curraghinalt lateral ramp also has the same trend. This structure is not represented as a separate entity in the model as its position and extent are not clearly defined.

On account of the presence of the subsidiary vein set associated with the deposit at Cavanacaw and the orientation of the Omagh Thrust, south-south-east- and east-north-east-trending structures are included as exploration criteria in the Cavanacaw model.[16]

Geochemistry

Geochemical data from the Curraghinalt and Cavanacaw deposits indicates that there are significant differences between the mineralisation at the two localities. Earls *et al.*[26] undertook a comprehensive review of the geochemistry of a wide range of host rock and vein samples from Curraghinalt, Cavanacaw, Golan Burn and other vein occurrences throughout the Sperrin Mountains.

Silver is associated with both Au (in electrum) and Pb (in galena) in the veins in both deposits. Although the mineralisation at Cavanacaw is considerably richer in Ag, there is a strong positive correlation between Au and Ag at Curraghinalt. In comparison to Cavanacaw, Curraghinalt veins have greater Bi and Cu concentrations and lower Pb, As and Sb concentrations. The Au contents of the Curraghinalt veins are correlated with those of Bi, and to a lesser extent of As, while at Cavancaw Au is associated with enrichment in Ag, As, Ce, Cu and Pb. The base metals Cu, Pb and Zn are all present in sulphides at Cavanacaw with galena being relatively common. The Curraghinalt mineralisation is distinctly poor in Pb and sphalerite has not been identified in the deposit.[26]

Earls *et al.*[26] also undertook a review of stream-sediment data from the Sperrin Mountains and compared this with the lithogeochemical data. Arsenic values are generally high over much of the Sperrins with the highest values occurring at Cavanacaw and other localities close to the Omagh Thrust. The distribution of Cu shows a stratigraphical control, with above average concentrations over the Dart and Glenelly Formations. Highly anomalous Pb values are observed south-west and north-east of Omagh in the vicinity of the Omagh Thrust and Cavanacaw. According to Earls *et al.*[26] Pb anomalies disappear rapidly along strike to the north-east and are not observed in stream sediment samples from the Curraghinalt area. Neither Curraghinalt nor Cavanacaw are associated with high Zn values in stream sediments.

DATA AND EXPLORATION CRITERIA

Based on the generalised deposit model for shear zone associated vein-gold mineralisation and the specific characteristics of the gold mineralisation in Northern Ireland a range of exploration criteria was defined for use in this analysis. The datasets used to provide information relating to these criteria are summarised in Table 3.

	Exploration criteria	Rationale	Data source	Evidence layers
MINERAL OCCURRENCES	**Known mineralisation**	Gold mineralisation is associated with the occurrence of other metallic and gangue minerals	NI Mineral Occurrence Database	Metallic minerals in bedrock; Metallic minerals in float; Gangue minerals
GEOCHERMICAL CRITERIA	**Geochemical anomalies for Au-Ag-Bi-As-Cu-Pb-Zn-Sb**	Indicator of proximity to mineralisation. Pathfinders for gold based on geochemical characteristics of orogenic gold deposits, ore mineralogy and documented associations	Tellus stream-sediment geochemistry (1 sample/2.15km^2)	Gridded geochemistry: Au, Ag, As, Pb, Cu, Zn; Panned gold occurrences
STRUCTURAL CRITERIA	**Proximity to 'first-order' transcrustal structures**	Crustal-scale faulting is linked to space creation at Curraghinalt.[26] Potentially important zones of fluid transport and control on second-order faults	1:250 000 scale mapped faults	Omagh Thrust; Basement lineaments
	Proximity to 'second-order' structures of preferred orientation	Structural control at a local level, ground preparation and enhanced permeability	1:250 000 scale mapped faults; Tellus magnetic, and electromagnetic data; regional gravity data	Structures filtered to retain those of certain preferred orientations: NE–SW, N–S, E–W to ESE–WNW (Cr), SSE–NNW (Cv), ENE–WSW (Cv)
STRATIGRAPHICAL CRITERIA	**Presence of pre-Dalradian rocks**	Potentially mineralised, but of limited extent in the study area	1:250 000 scale geological map	Generalised pre-Dalradian rocks
	Presence of specific Dalradian Formations	All significant vein gold occurrences are associated with Dalradian rocks	1:250 000 scale geological map	Dalradian formations
	Presence of post-Dalradian rocks	Potential hosts for remobilised Caledonian gold	1:250 000 scale geological map	Generalised post-Dalradian rocks
	Presence of psammitic units	More favourable rheological properties for vein development than ductile pelite horizons	Relative favourability assigned to individual Dalradian formations (Table 6)	
	Presence of graphitic pelite horizons	Observed association between mineralisation and graphitic pelite	Relative favourability assigned to individual Dalradian formations (Table 6	

ALTERATION	**Wall-rock alteration - potassic, argillic, carbonate, propylitic**	Alteration may be used as a vector to mineralisation but intensity and extent are variable	Unavailable	

Table 3 Main exploration criteria for vein gold mineralisation in Northern Ireland and associated evidence layers utilised. Annotated vectors were only applied to a single model: Cr, Curraghinalt; Cv, Cavanacaw.

Stratigraphical criteria

The prospectivity analysis utilised the 1:250 000 scale geological linework published by the GSNI.[27] The geology of the study area was re-classified into pre-Dalradian, Dalradian and post-Dalradian groupings. Sub-divisions of the Dalradian Supergroup were retained so that different fuzzy membership values could be assigned to individual Dalradian formations, based on their perceived prospectivity for gold mineralisation (Table 2). The only exploration criterion identified which was not incorporated in the modelling was alteration. This was omitted due to lack of an appropriate alteration dataset.

Structural criteria

Structural data was derived from two sources: geological mapping and geophysical data analysis. Structural exploration criteria are detailed in Table 4.

Criteria	**Significance**	
	Curraghinalt	*Cavanacaw*
Proximity to Omagh Thrust	h	m
Proximity to basement lineaments	l	h
Proximity to NE–SW structures	h	l
Proximity to N–S structures	l	h
Proximity to E–W to ESE–WNW structures	h	na
Proximity to SSE–NNW structures	na	m
Proximity to ENE–WSW structures	na	m
Au in stream-sediment samples	h	h
Ag in stream-sediment samples	m	m
As in stream-sediment samples	m	h
Cu in stream-sediment samples	l	m
Pb in stream-sediment samples	l	h
Zn in stream-sediment samples	l	l

Table 4 The relative significance assigned to 'first-order' transcrustal structures, other structural vectors and geochemical criteria in the two prospectivity models used in this study, referred to as the 'Curraghinalt' and 'Cavanacaw' models. Significance: h, high; m, medium; l, low; na, not applicable

Mapping

Mapped faults and shear zones, as shown on the 1:250 000 scale geological map of Northern Ireland, are direct evidence of deformation (Fig. 1). More than a thousand 'mapped' structures occur within the study area. The most prominent of these is the Omagh Thrust.[27] The Omagh Thrust and basement lineaments were treated separately from other structures in this analysis due to their regional influence and major control on the location of mineralisation in the study area.

Geophysics

Aeromagnetic and electromagnetic (EM) data from the Tellus airborne survey were incorporated into the prospectivity analysis. The survey was flown at an elevation of 56 m in rural areas rising to 240 m in urban areas with survey lines spaced at 200 m intervals. Full details of the survey are documented in Beamish *et al.*[6]. In addition BGS regional gravity data was included in this study as it is useful for identifying major regional crustal structures. The density of gravity data coverage for Northern Ireland is approximately 1 station per 1.25 km^2.

A series of high-resolution regional images of the magnetic, electromagnetic and gravity data were analysed in ArcGIS and the main structural elements identified and digitised (Fig. 2). The main features obtained from each dataset were:

1. Magnetic data - lineaments related to faults, shear zones, fold structures and dyke swarms;
2. EM data - principal EM conductors, fault-related conductors and anomaly offsets;
3. Gravity data - lineaments attributed to faults and deep seated structures.

Magnetic lineaments were extracted from various images, chiefly the reduced-to-pole field, the residual magnetic field derived by upward continuation to 500 m, and the 1st vertical derivative field. The residual and 1st vertical derivative field magnetic images were particularly effective in identifying short wavelength, near-surface features including faults, magnetic horizons and minor intrusions. The horizontal gradient of the magnetic pseudogravity was particularly successful in identifying many short wavelength lineaments primarily associated with fold structures and structural trends.

Mapped faults, shear zones and geophysical lineaments were treated as a single evidence layer in the modelling and it is assumed that they represent the same style of deformation.

Geochemical criteria

Stream-sediment geochemical data was incorporated in the prospectivity analysis. The basic premise underlying the use of stream sediments in mineral exploration is that they are composite samples produced by erosion and weathering and thus represent the source catchment area, including any contained metalliferous mineralisation, of the stream drainage network. Regional stream-sediment data are therefore preferred to regional soil data in this type of study.

In the Tellus project stream-sediment samples were collected from first- and second-order streams over eastern Northern Ireland at an average density of 1 sample per 2.15 km^2. For western Northern Ireland data from stream-sediment samples (39 analytes) collected in an earlier programme were integrated with the Tellus dataset and have been used in the present study. In total 1476 stream-sediment sample sites are located within the study area.

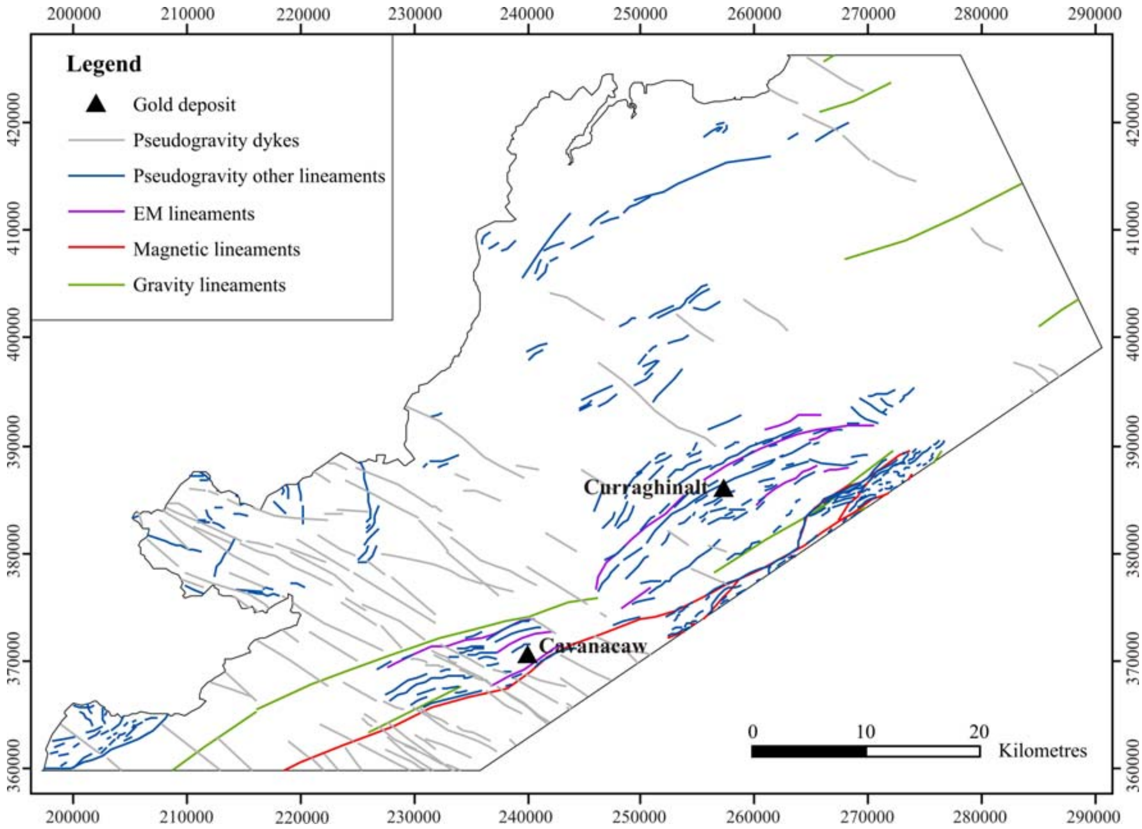

Fig. 2 Lineaments picked from the Tellus geophysical data. Note features representing dykes were not included in the analysis

The choice of elements used in this analysis was guided by the target mineral deposit type and by a review of previous geochemical data for the area (Table 5). Gridded geochemical maps, based on percentiles, were created for each of the selected elements. It is notable that Ag displays much less variation in concentration than Au and other potential pathfinder elements indicated by the deposit models. This suggests that Ag in stream sediments is potentially of limited value as an indicator of gold mineralisation in this terrane. Sb and Bi were not included on account of their generally low values within the stream-sediment dataset.

Element	Maximum	Mean	Median	75%	90%	95%	98%	99%
Au	3485	18	1	2	8	25	91	350
Ag	9	0.7	0.5	0.5	1	2	3	5
As	1400	27	12	25	57	96	150	231
Cu	162	31	26	37	58	71	87	94
Pb	207	37	33	42	54	65	76	93
Zn	1524	140	123	159	226	291	394	477

Table 5 Summary univariate statistics for stream-sediment data for the study area. All values in ppm, except Au in ppb (*n=1474* for all elements with the exception of Au, *n=1376*)

Mineral occurrences

Selected mineral occurrences from the GSNI Mineral Occurrence Database (MOD) were incorporated into the prospectivity analysis. This database contains records of 430 mineral occurrences in Northern Ireland 154 of which occur in the study area. The database was filtered to retain occurrences of the following types:

1. Metallic sulphides-oxides-carbonates and sulphates in bedrock (*n=31)*;
2. Metallic sulphides-oxides-carbonates and sulphates in float (*n=6)*;
3. Gangue minerals (*n=7)*.

A relatively low weighting was assigned to this data in the prospectivity analysis because some records in the database are incomplete while some others of, say, pyrite, are more likely to be related to diagenesis and metamorphism than to mineralisation.

Observations of visible gold grains made during collection of panned heavy mineral concentrates in the Tellus geochemical sampling were utilised in the analysis (*n=19*). Occurrences of gold in bedrock were excluded from the modelling as these were subsequently used to validate the results of the prospectivity analysis.

Data processing

A proximity analysis ('buffering') was performed on linear features (faults, geophysical lineaments) and point themes (mineral occurrences) such that the weighting of a particular feature in the analysis decreases with increasing distance from that feature. Features in each of the themes were buffered at variable intervals. The datasets were assigned variable buffer distances depending on the likely extent of influence of a particular feature.

PROSPECTIVITY MAPPING USING FUZZY LOGIC

Each evidential theme in the exploration model for vein-hosted gold mineralisation in Northern Ireland (Table 3) was assigned fuzzy membership values on the basis of the mineral deposit model. Table 6 and Table 7 show the fuzzy membership values allocated to evidential themes common to both the Curraghinalt and Cavanacaw models. Tables 8–11 show fuzzy membership values for criteria which differ between the two models. The weighting assigned to each evidence layer is also dependent on the relative importance of one dataset against another.

Formation name or stratigraphic grouping	Fuzzy membership value
Glengawna Formation	*0.70*
Mullaghcarn Formation	*0.61*
Dungiven Formation (carbonates)	*0.53*
Dungiven Formation (non-carbonate)	*0.49*
Glenelly Formation	*0.49*
Dart Formation	*0.49*
Newtownstewart Formation	*0.49*
Londonderry Formation	*0.40*
Ballykelly Formation	*0.40*
Claudy Formation (Dart equivalent)	*0.49*
Killeter Formation (Newtownstewart equivalent)	*0.49*
Aghyaran Formation (Dungiven equivalent)	*0.49*
Mullyfa Formation (Dart equivalent)	*0.49*
Lough Eske Formation	*0.40*
Lough Mourne Formation	*0.40*
Croaghgarrow Formation (Glengawna equivalent)	*0.70*
Pre-Dalradian	*0.30*
Post-Dalradian	*0.20*

Table 6 Fuzzy membership values assigned to Dalradian formations

Buffer distance (km)	0.0–0.5	0.5–1.0	1.0–1.5	1.5–2.0	2.0–2.5	2.5–3.0	3.0–3.5	3.5–4.0
	Fuzzy membership values							
Panned gold occurrence	*0.70*	*0.61*	*0.53*	*0.44*	*0.36*	*0.27*	*0.19*	*0.10*
Metallic minerals in bedrock	*0.20*		*0.17*		*0.13*		*0.10*	
Metallic minerals in float	*0.20*				*0.10*			
Gangue minerals	*0.20*	*0.17*	*0.13*	*0.10*				

Table 7 Fuzzy membership values assigned to buffers around known mineral occurrences

Buffer distance (km)		0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8
	Model	*Fuzzy membership values*							
Omagh Thrust	*Cr*	*0.70*	*0.61*	*0.53*	*0.44*	*0.36*	*0.27*	*0.19*	*0.10*
	Cv	*0.50*	*0.44*	*0.39*	*0.33*	*0.27*	*0.21*	*0.16*	*0.10*

Table 8 Fuzzy membership values assigned to buffers around the Omagh Thrust (Cr, Curraghinalt model; Cv, Cavanacaw model)

Buffer distance (km)		0–1	1–2	2–4	4–6	6–8	8–10	10–12	12–16
	Model	*Fuzzy membership values*							
Basement lineaments	*Cr*	*0.40*	*0.36*	*0.33*	*0.29*	*0.25*	*0.21*	*0.18*	*0.10*
	Cv	*0.70*	*0.63*	*0.55*	*0.48*	*0.40*	*0.33*	*0.25*	*0.10*

Table 9 Fuzzy membership values assigned to buffers around basement lineaments (Cr, Curraghinalt model; Cv, Cavanacaw model)

Buffer distance (km)		0–1	1–2	2–3	3–4
Orientation	**Model**	*Fuzzy membership values*			
NE–SW	*Cr*	*0.60*	*0.43*	*0.27*	*0.1*
NE–SW	*Cv*	*0.45*	*0.33*	*0.22*	*0.1*
N–S	*Cr*	*0.40*	*0.30*	*0.20*	*0.1*
N–S	*Cv*	*0.70*	*0.50*	*0.30*	*0.1*
E–W to ESE–WNW	*Cr*	*0.70*	*0.50*	*0.30*	*0.10*
SSE–NNW	*Cv*	*0.50*	*0.40*	*0.30*	*0.10*
ENE–WSW	*Cv*	*0.45*	*0.33*	*0.22*	*0.10*

Table 10 Fuzzy membership values assigned to buffers around ‘second-order’ structures (Cr, Curraghinalt model; Cv, Cavanacaw model)

Curraghinalt model					
Percentiles	**99**	**95**	**90**	**75**	**50**

Curraghinalt model					
	Fuzzy membership values				
Au	*0.70*	*0.60*	*0.50*	*0.40*	*0.20*
Ag	*0.50*	*0.40*	*0.30*	*0.20*	*0.10*
As	*0.50*	*0.40*	*0.30*	*0.20*	*0.10*
Cu	*0.40*	*0.35*	*0.30*	*0.20*	*0.10*
Pb	*0.25*	*0.20*	*0.15*	*0.10*	*0.10*
Zn	*0.20*	*0.15*	*0.10*	*0.10*	*0.10*
Cavanacaw model					
	Fuzzy membership values				
Au	*0.70*	*0.60*	*0.50*	*0.40*	*0.20*
Ag	*0.60*	*0.50*	*0.40*	*0.30*	*0.20*
As	*0.60*	*0.50*	*0.40*	*0.30*	*0.20*
Pb	*0.60*	*0.50*	*0.40*	*0.30*	*0.20*
Cu	*0.40*	*0.35*	*0.30*	*0.20*	*0.10*
Zn	*0.25*	*0.20*	*0.15*	*0.10*	*0.10*

Table 11 Fuzzy membership values assigned to each class in the geochemistry data theme for the two models

A map of mineral potential was created by combining the evidential themes in two stages using fuzzy logic operators (Fig. 3). Five fuzzy set operators are frequently used for the integration of fuzzy information layers (Table 12).[2,12,61]

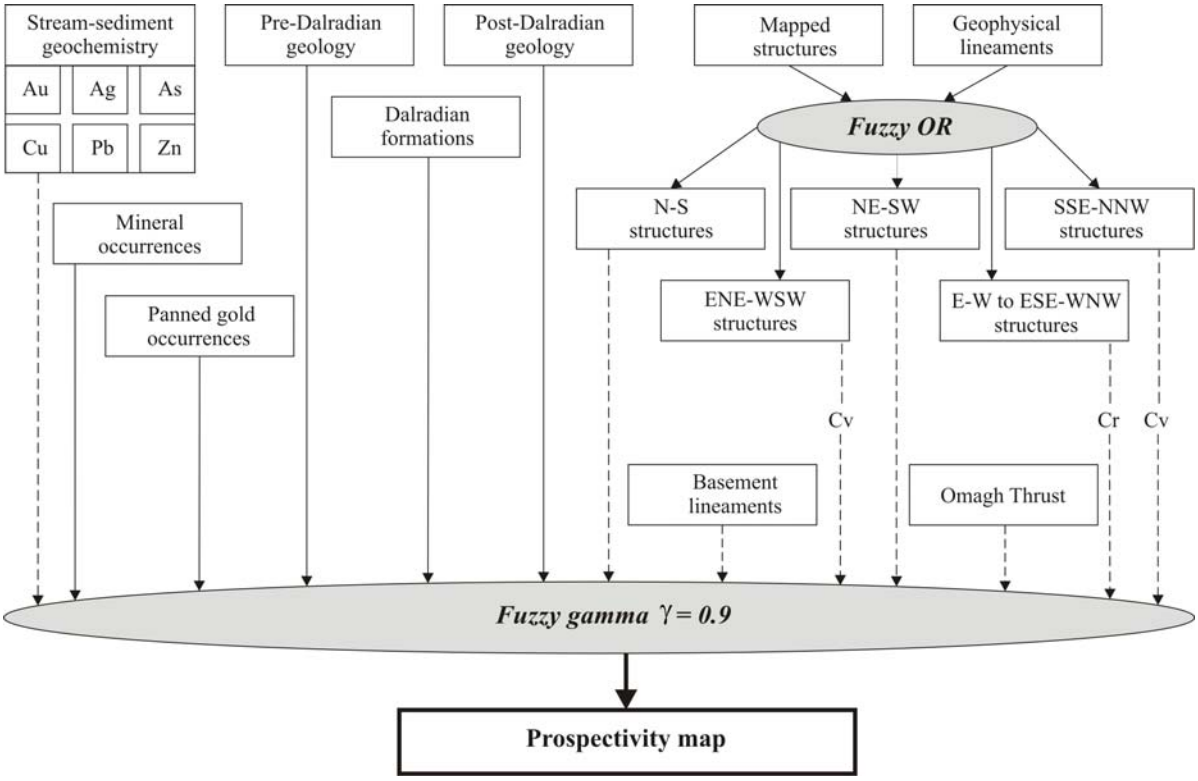

Fig. 3 Schematic inference diagram illustrating the data integration process for the prospectivity analysis. Solid lines indicate evidential themes applied to both models, while dashed lines indicate criteria applied to a single model, or applied with different weightings in each one. (Cr, Curraghinalt model; Cv, Cavanacaw model)

Fuzzy operator	Expression
Fuzzy AND	$\mu_{combination} = MIN(\mu_A, \mu_B, \mu_C \ldots)$
Fuzzy OR	$\mu_{combination} = MAX(\mu_A, \mu_B, \mu_C \ldots)$
Fuzzy algebraic product	$\mu_{combination} = \Pi^n_{i=1} \mu_i$
Fuzzy algebraic sum	$\mu_{combination} = 1 - \Pi^n_{i=1} (1 - \mu_i)$
Fuzzy gamma	$\mu_{combination} = (\Pi^n_{i=1} \mu_i)^{1-y} (1 - \Pi^n_{i=1}(1 - \mu_i))^\gamma$

Table 12 Fuzzy logic operators as described by Bonham-Carter[12]

In the first stage the structural linework derived from the 1:250 000 scale geological map and the geophysical lineament dataset were combined using the fuzzy OR operator (Table 12). When maps are combined using the OR operator the output membership value is dictated by the maximum membership values of the input maps for a particular point.[12] The OR operator ensures no double counting of interpreted lineaments which coincide with known faults. The combined structural dataset was filtered to include only structures with specific orientations based on empirical observations of structures at Curraghinalt and Cavanacaw (Table 4). For each preferred direction a window of ± 10º was utilised so that vectors with orientations close to the specified direction were also included.

The second stage of the integration process combined the fuzzy membership values from each theme using the fuzzy gamma operator. The fuzzy gamma (γ) operator is a combination of fuzzy algebraic product and fuzzy algebraic sum. Its use is a compromise between the 'increasive' nature of fuzzy algebraic sum and the 'decreasive' effects of the fuzzy algebraic product (Table 12). γ values range between 0 and 1 and when γ is 0, the combination is the same as fuzzy algebraic product and, when γ is 1, it equals the fuzzy algebraic sum. The effect of selecting different γ values was investigated by Bonham-Carter[12]. Previous studies suggest γ values in the region of 0.9 are most suitable for prospectivity mapping,[2,23,41,55] although other studies have utilsed lower γ values of around 0.75.[13,44,46] Choice of γ value is ultimately subjective and several were tested in this analysis. A value of 0.9 produced the optimum results and was used in this study. The process was run separately for each deposit model allowing the individual characteristics of Curraghinalt and Cavanacaw to be taken into account.

RESULTS AND VALIDATION

The results of the analysis based on the two separate deposit models are shown in Fig. 4 and Fig. 5 and summarised in Table 13. Validation of the results of the analysis is important to determine how accurately the exploration criteria have been translated into the prospectivity models. Since the exploration criteria are largely based upon two deposits this can be judged in part by the spatial correlation between these deposits and the prospectivity maps. Secondly, it is important to determine the reliability of the results of the analysis in order to understand its value for identifying new gold targets. For the purpose of validating the modelling the 'other vein-hosted gold occurrences' described previously can be considered 'unknown' to the model.

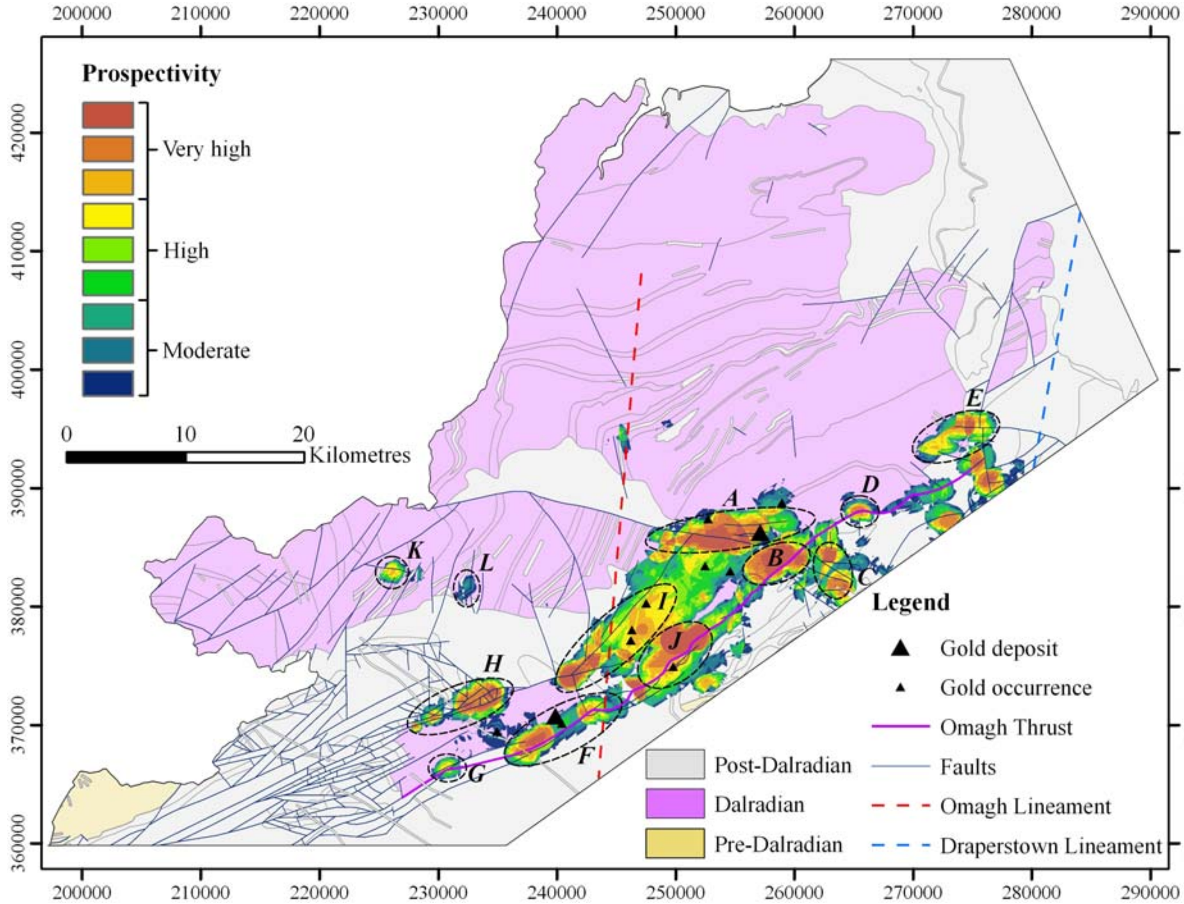

Fig. 4 The distribution of prospectivity based on the Curraghinalt model. Areas of highest prospectivity, labelled *A–L*, are discussed in the text. Geological linework from GSNI[27] © Crown copyright.

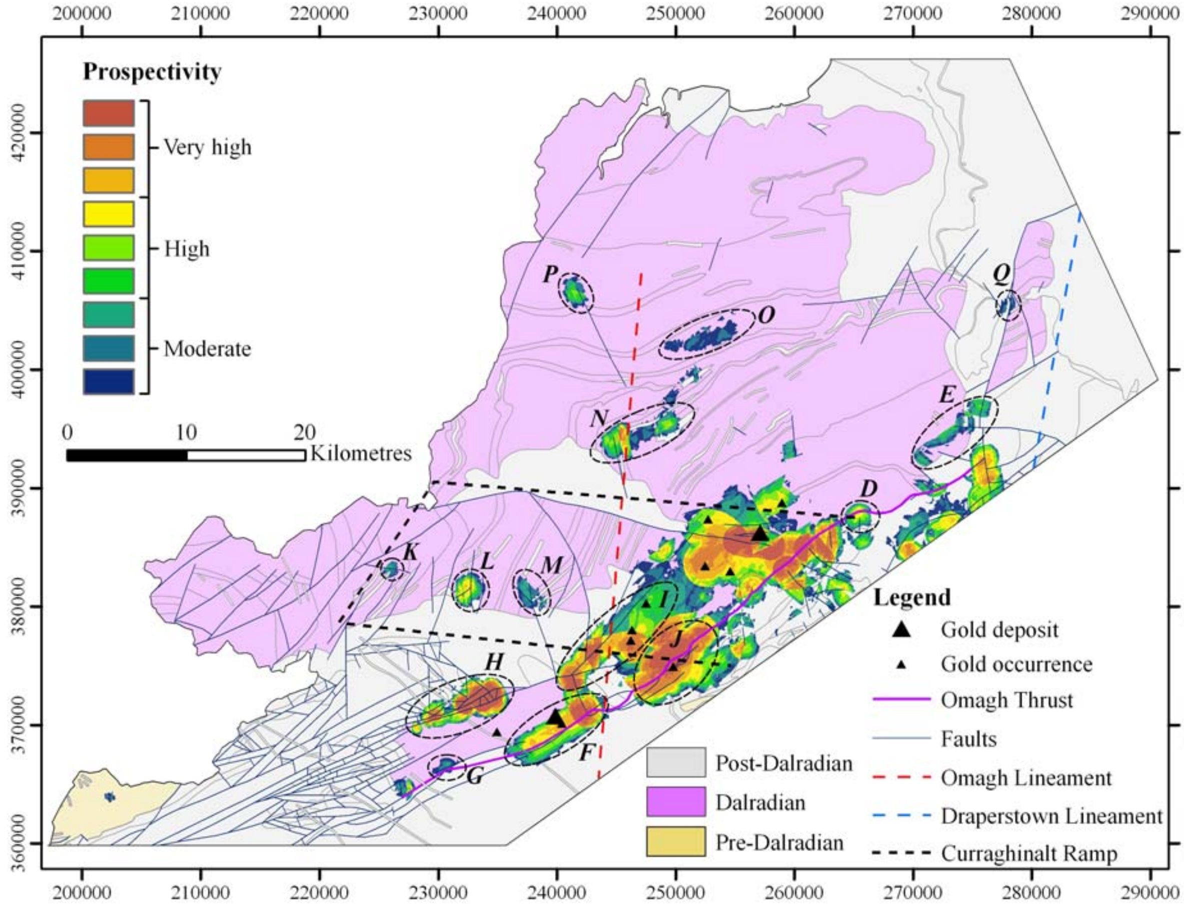

Fig. 5 The distribution of prospectivity based on the Cavanacaw model. Areas of highest prospectivity, labelled *D–Q*, are discussed in the text. Postulated extent of the Curraghinalt Ramp structure is also shown. Geological linework from GSNI[27] © Crown copyright.

Area	Approx. extent (km^2)	Geology	Incidence of favourable structural buffers*	Maximum Au value in stream sediments (ppb)	Incidence of gold in panned concentrates*	Influence of mineral occurrences	Influence of Omagh Thrust*	Influence of basement lineaments*
A	26	Mullaghcarn, Glengawna, Glenelly, Carboniferous	10 NE, 1 N, 4 E–ESE	3485	5	1	Moderate	Moderate
B	15	Mullaghcarn, Ordovician	5 NE, 1 N, 3 E–ESE	842	2	6	High	Low
C	9	Post-Dalradian, Ordovician, intrusives	3 NE, 2 N, 4 E–ESE	70	1	2	High	Low
D	4	Mullaghcarn , Ordovician	2 NE, 1 N, 1 E–ESE	31	0	2	High	Low
E	20	Glenelly, Carboniferous	2 NE, 1 N, 3 E–ESE	2	4	4	Moderate	Moderate
F	17	Mullaghcarn, Devonian, Carboniferous	2 NE, 2 E–ESE (Cr), 1 SSE, 6 ENE	1094	6	0	High	Moderate
G	4	Mullaghcarn, Carboniferous	2 NE, 1 E–ESE	22	1	0	High	Low
H	22	Mullaghcarn, Carboniferous	4 NE, 5 N, 5 E–ESE, 3 SSE, 9 ENE	350	4	0	Moderate	Low
I	35	Mullaghcarn, Carboniferous	1 NE, 1 N, 1 E–ESE, 1 SSE, 7 ENE	59	6	2	High	High
J		Mullaghcarn, Ordovician, Carboniferous	5 NE, 1 E–ESE, 3 ENE	50	6	4	High	Moderate
K	7	Claudy	4 NE, 2 N, 1 E–ESE, 1 ENE	177	5	2	None	Low
L	4	Dungiven, Carboniferous	1 NE, 2 N, 1 ENE	0.5	3	3	None	Low
M	6	Newtownstewart, Dungiven	1 NE, 1 N, 1 SSE	1	6	3	None	Moderate
N	14	Dungiven, Dart, Newtownstewart	5 NE, 1 N, 6 ENE	10	6	3	None	High
O	11	Claudy	3 NE, 4 ENE	18	7	2	None	High
P	6	Claudy	2 NE, 1 N, 1 SSE, 2 ENE	36	3	0	None	Moderate
Q	3	Dart, Dungiven, Carboniferous	1 NE, 1 N, 2 SSE	2	2	0	None	Moderate

Table 13 Summary of exploration criteria contributing to the prospectivity of each area displayed on Fig. 4 and Fig. 5 *refer to exploration criteria falling within the area and/or the influence of exploration criteria on the area as a result of buffering

Gold favorability maps showing the areas of highest potential according to each of the models were compared with known occurrences to assess their predictive capability (Fig. 4 and Fig. 5). The areas of highest potential were divided into three prospectivity classes; very high, high, and moderate and displayed using a gradational colour scale.

Regional prospectivity analysis, covering an area of 3074 km^2, using the two models has identified several areas prospective for vein-hosted gold mineralisation disposed in four groups. There is generally a good correlation between the validation points and the distribution of gold prospectivity. The Curraghinalt and Cavanacaw deposits are located within areas of very high and high prospectivity on their respective maps. All of the known occurrences are located within the area of highest potential on the Curraghinalt map and all but one occurrence falls within this area on the Cavanacaw map. Both models clearly delineate the 'Lack – Curraghinalt zone', with a belt of almost continuous high prospectivity extending from Glenlark in the north-east to Cavanacaw in the south-west and beyond.

Curraghinalt-Golan Burn zone and eastwards (areas A–E)

Three prominent areas of high prospectivity are evident on the map generated by the Curraghinalt model, extending from the eastern limit of the Newtownstewart Basin, through Golan Burn and Curraghinalt (*A*), over the Omagh Thrust (*B*) and southwards beyond the Dalradian outcrop (*C*). On the map derived from the Cavanacaw model this region displays high prospectivity, although discrete zones are less pronounced. The prospective zone associated with the Curraghinalt deposit (*A*) extends westwards for approximately 7 km, before dying out on the eastern side of the Newtownstewart Basin. Both Curraghinalt and Golan Burn are offset from the area of maximum prospectivity within zone *A*. The three prospective areas (*A*, *B* and *C*) lie on the same trend as the major fault bounding the southern side of the Newtownstewart Basin.

Farther east the prospective areas are generally smaller and more focused, with a bull's eye target straddling a distinct jog in the Omagh Thrust (*D*). Farther east another prospective area (*E*) is prominent on the Curraghinalt map. It is associated with the Dalradian Glenelly Formation and subordinate Carboniferous sedimentary rocks, and is also influenced by both the Omagh Thrust and Draperstown Lineament.

The Lack Inlier (areas F–J)

A number of prospective areas occur around the Lack Inlier, all associated with the Mullaghcarn Formation. As would be expected the analysis based on the Cavanacaw model returns higher levels of prospectivity in the vicinity of the Cavanacaw deposit. Cavanacaw and Creevan Burn fall within an elongated zone of high to very high prospectivity on the south-eastern side of the Lack Inlier (*F*), offset to the west by around 1.5 km from the point of maximum prospectivity. In contrast, on the map based on the Curraghinalt model, Cavanacaw and Creevan Burn are located in an area of lower prospectivity between two discrete highs. Further isolated zones of moderate to high prospectivity occur along the southern boundary of the Lack Inlier, west of Cavanacaw e.g. area *G*. Both maps include a prominent, elongate area of very high prospectivity on the northern side of the Lack Inlier, extending into the Carboniferous Omagh-Kesh Basin (*H*). Another largely continuous area of high to very high prospectivity extends from the north-east corner of the Lack Inlier eastwards, towards Rylagh and Erganagh Burn (*I*). This area is underlain by both Dalradian and Carboniferous rocks.

Along strike to the north-east of Cavanacaw an extensive area (*J*) of very high prospectivity is evident on Fig. 4 and Fig. 5. The area is mostly underlain by the Mullaghcarn Formation but it straddles the Omagh Thrust, extending southwards over the Ordovician TIC. Zone *J* is of particular interest as it lies along strike from Cavanacaw and is also located at the eastern end of a series of prospective zones (*K, L, M*) trending west-north-west which passes through the gold occurrences of Rylagh and Erganagh Burn.

North of the Omagh-Kesh Basin (areas K–M)

Three areas of high to moderate prospectivity occur to the west of the main prospective area associated with the 'Lack – Curraghinalt zone'. Two of these are present in the results of both models (*K, L*). These areas are situated within an east-west-trending package of Dalradian rocks (Claudy, Dungiven, Newtownstewart Formations), containing pre-Caledonian metabasite intrusions and bounded to the north and south by Carboniferous basins. The prospective areas are structurally controlled with *L* and *M* located along the faulted boundary of the Carboniferous Omagh-Kesh Basin.

Northern and eastern outliers (areas N–Q)

A zone of moderate to high prospectivity occurs directly north of Rylagh and Erganagh Burn on the Cavanacaw map. It coincides with the change in strike of the Dalradian rocks, close to the hinge of the Sperrin Nappe, and the inferred trace of the Omagh Lineament (*N*), which potentially links it with the occurrences to the south. To the north-east a zone of moderate prospectivity (*O*) is underlain by the Claudy Formation, proximal to the hinge of the Sperrin Nappe. The northernmost prospective area (*P*), only evident on the Cavanacaw map, is associated with a north-north-west-trending fault. A further outlier (*Q*) occurs to the east of the study area, associated with the Dalradian Dart Formation and Carboniferous sedimentary rocks, and is influenced by the Draperstown Lineament. These prospective areas, remote from the 'Lack – Curraghinalt zone', all occur close to inferred basement lineaments.

DISCUSSION

Many of the target areas defined by the prospectivity analysis coincide with known vein-hosted gold occurrences while others occur in areas delineated as prospective by previous work e.g. Earls *et al.*[26] The prospectivity analysis has generated considerably more focused targets for follow-up investigation compared with previous regional studies. Of particular interest are the under-explored areas outside the Lack-Curraghinalt zone including K, L, M, N, O, P and area Q located on the Tow Valley Fault. The Newtownstewart-Baronscourt-Castlederg area in which targets K–M are located is associated with extensive geochemical anomalies for As, Zn and Ba in Tellus soils data. Vein-hosted barite-base-metal mineralisation is also reported from the Baronscourt area. Although the metabasite intrusions may represent a potential source of gold pre-Caledonian intrusive rocks have not been considered by previous authors to play a role in the genesis of these deposits.

The modelling confirms that the Lack Inlier and its environs extending eastwards are highly prospective, as indicated by areas of relatively high prospectivity extending south-west of Cornavarrow. The prospectivity maps also suggest that the faults bounding the northern and eastern side of the Lack Inlier are highly prospective.

Although there is generally a good correlation between known gold occurrences and the distribution of gold prospectivity it is important to note that the deposits at Curraghinalt and

Cavanacaw do not coincide with the areas of maximum prospectivity generated by the modelling. This may be attributed to a combination of factors, including:

1. Incomplete understanding of geological controls on the location of mineralisation;
2. Inability to accurately translate the exploration criteria into the prospectivity models;
3. Utilisation of regional scale datasets in the analysis with deposit models based on local data;
4. General data incompatibility issues e.g. the airborne geophysics and geochemical data have very different sample intervals. The issue of integrating different scale datasets in prospectivity analysis has not been widely explored in the literature and consequently the effect on the modelling remains unclear;
5. The subjective nature of fuzzy logic modelling. This approach is strongly dependent on expert judgement to determine the key exploration indicators based on the mineral deposit model, to assign weightings, zones and styles of influence, and to select the fuzzy logic operators used to combine the datasets.

Although the gold favourability maps have considerably reduced the search area for gold mineralisation in the study area (3074 km^2) the total prospective zone remains relatively large at approximately 350 km^2. This is a consequence of using regional scale datasets which are not optimal for the delineation of smaller prospective targets.

Overall there is close correlation between the Curraghinalt and Cavanacaw model results, with some variations in the position, extent and degree of prospectivity of the target areas. The differences in the results generated by the two models, notably areas M to Q on the Cavanacaw map and the intensity of prospectivity in the south-east corner of the Lack Inlier results from the different significance attributed to structural and geochemical parameters in each model (Table 4 and discussed in deposit-scale variations). The areas prospective or more prospective on the Cavanacaw map result from a combination of favourable structural and geochemical criteria (Table 13), principally high values for arsenic, lead and copper in stream sediments and the influence of the Omagh Lineament and other structural vectors which are allocated lower or no significance in the Curraghinalt exploration model.

In addition to delineating areas potentially favourable for gold mineralisation the prospectivity mapping has provided some new insight into possible regional controls on the location of mineralisation and into the geology of this area:

1. *Westward extension of the Curraghinalt lateral ramp*: the series of prospective areas extending from the eastern end of the Newtownstewart Basin, through Golan Burn and Curraghinalt, and continuing eastwards over the Omagh Thrust, falls on a linear west-north-west trend. These prospective areas coincide with the major east-west-trending fault bounding the southern side of the Newtownstewart Basin and its projected extension eastwards. This is consistent with the work of Earls *et al.*[26] who identify this zone as an important target. A second series of prospective areas occurs to the north of the Omagh-Kesh Basin, also orientated west-north-west, passing through Rylagh Burn and a second area of very high prospectivity (*J*). These linear prospective areas may be related to major structural boundaries, which could represent important zones of fluid flow. A postulated westward extension of the Curraghinalt lateral ramp, generally regarded as a critical control on the location of the mineralisation at Curraghinalt, would coincide with these areas. Accordingly the fault bounding the southern side of the Newtownstewart Basin could be related to the northern boundary of the ramp structure with the southern boundary

obscured by the Omagh-Kesh Basin. If these prospective zones are associated with the Curraghinalt Ramp then its extent or influence may extend further south than previously considered. The fault bounding the southern side of the Newtownstewart Basin is deemed highly prospective given the distribution of prospectivity and its extension into the Curraghinalt area (Fig. 5).

2. *Extent of the prospective Glengawna Formation:* a further consideration relates to the mapping of the Dalradian in the 'Lack - Curraghinalt zone'. The Dalradian rocks associated with the two targets to the north of the Lack Inlier (H, I) are mapped as Mullaghcarn Formation and no Glengawana Formation has been formally recognised (Fig. 1).[27] There are, however, definable packages of graphitic semipelite and pelite at various levels within the Lack Inlier, which are considered to indicate the presence of Glengawna Formation.[15] An extension of the Glengawna Formation into the Lack Inlier would coincide with these two important targets. This is significant as proximity to the Glengawna Formation is suggested to play a role in the location of mineralisation.

3. *Prospectivity of the Sperrin Fold zone*: fold crests are widely recognised as sites of space creation and mineralisation.[39,60] Our analysis has identified two prospective areas proximal to the hinge zone of the Sperrin Nappe. In addition this fold zone coincides with the projected trace of the Omagh Lineament, a potentially important locus for fluid flow.

4. *The relationship between volcanic-hosted gold mineralisation and Dalradian-hosted gold*: the gold mineralisation at Crosh coincides with the eastern side of the prospective trend located to the north of the Omagh-Kesh Basin. The mineralisation is volcanic-hosted but is situated in close proximity to the Omagh Thrust and the Mullaghcarn Formation. Given the importance of the footwall ramp in the mineralisation process it is not implausible to envisage movement of Caledonian mineralising fluids through the TIC.

CONCLUSIONS

Regional scale prospectivity analysis over the Sperrin Mountains of Northern Ireland using a fuzzy logic approach and integrating new data from the Tellus geochemical and geophysical surveys has identified several areas prospective for vein-hosted gold mineralisation. Many of these either coincide with known occurrences of gold mineralisation or with areas considered prospective based on previous work e.g. Earls *et al.*[26], validating the process and model results. Those areas of high prospectivity in which there are no known gold occurrences are considered to be favourable targets for further exploration. A number of these are located outside the main 'Lack – Curraghinalt zone' and should be followed up.

The use of separate models for the Curraghinalt and Cavanacaw deposits in our analysis was based upon their distinct geochemical and structural features. However, a close correlation is observed between the main targets generated by the two models. It is not possible to conclude if one model is generally superior to the other for exploration in the Sperrin Mountains. We suggest that continued refinement of both models, using higher resolution datasets wherever possible, is the preferred way ahead. The incorporation of additional criteria relevant to the mineralisation into the modelling, supported by appropriate datasets, will in general improve the reliability of the results. The fuzzy logic approach has proved to be a flexible technique for testing the importance and relevance of different datasets to gold exploration in Northern Ireland, whilst incorporating expert knowledge of the deposits.

The results of the modelling suggest the exploration criteria have been successfully translated into the model and similar criteria could be used for prospectivity analysis in similar terranes elsewhere. The approach described for Northern Ireland could be applied to the Scottish Dalradian but without modern, high resolution airborne geophysical data it would not be possible to resolve the levels of structural detail attained from the Tellus survey.

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