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THE TYRONE IGNEOUS COMPLEX: A POTENTIAL SOURCE OF CRITICAL RAW MATERIALS IN NORTHERN IRELAND?

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Abstract

Critical raw materials [CRMs] are commodities of importance for which there is a significant risk of supply shortage. Securing these materials is paramount to ensure the UK and EU can meet emissions targets, as these elements are essential components in renewable energy and other critical technologies and manufacturing. The Caledonian-Appalachian orogenic belt hosts globally significant resources of CRM-bearing base- and precious-metal mineralisation with exploration development potential along its length, including numerous volcanogenic massive sulphide [VMS], porphyry, epithermal and orogenic Au deposits. The Tyrone Igneous Complex [TIC] of Northern Ireland represents an arc-ophiolite complex preserved in the Irish Laurentian sector of the orogen and contains numerous occurrences of mineralisation of varying age, style and metal content. These rocks are correlated with the VMS-rich Annieopsquotch Accretionary Tract of Newfoundland, although no resources have been defined in Northern Ireland. Here, we present a detailed account of VMS, orogenic, porphyry, intrusion-related and epithermal-style mineralisation found in the TIC through detailed field observations, petrography, and geochemical constraints. We demonstrate that these mineralisation styles relate to the evolving Grampian Orogeny and that these rocks may have potential for hosting CRMs.

Executive summary

The move towards global net-zero emissions has heightened the need for Critical Raw Materials [CRMs], which are vital for green-energy technologies and other critical technologies and manufacturing. CRMs are materials that are difficult to substitute and for which the supply chain is vulnerable to disruption. This paper assesses the potential of the Tyrone Igneous Complex [TIC] in Northern Ireland, a volcanic arc-ophiolite complex formed during the Grampian orogenic event, as a source for CRMs. This potential is studied through an integrated approach to field-work, petrography, and geochemistry to characterise

various styles of mineralisation. Results show that the TIC is host to volcanogenic massive sulphide, orogenic gold, porphyry, and epithermal systems, which all have potential for CRM enrichment, and are linked to the tectonic evolution of the Laurentian margin. However, the complex is underexplored and further study is required to gain a better understanding of the metal enrichments and genesis of these systems.

Introduction

The search for critical raw materials [CRMs] has become one of the key areas of collaborative



research in economic geology, involving partners from academia, industry, and government. Their criticality is due to well-established economic and geopolitical desires to reach net zero carbon emissions targets and providing raw materials for technologies needed for the green-energy transition (e.g. Deady *et al.* 2023). There are fears over security of CRM supply because they are typically byproducts and coproducts of base and precious-metal mining, are rarely found alone in economically viable concentrations, have a heterogeneous global distribution with limited, often national state-controlled refining capacity, and their global markets are often opaque and unpredictable. Consequently, a better characterisation of enrichment processes for CRMs within the Earth's crust is required, including their spatial and temporal distribution within the wide variety of deposits preserved in orogenic belts. A better understanding of these processes may help us recognise new sources of CRMs and potentially enhance supply security for the UK and EU.

The prospectivity for base and precious metals, as well as CRMs varies significantly between deposit types, adding to the complexity of this issue. Metal prospectivity for deposit types relevant to this contribution are detailed below:

- Volcanogenic massive sulphide deposits [VMS] are globally mined for Cu, Zn, Pb, Ag and/or Au, and can be important hosts for several CRMs, including Ga, Ge, Co, Cd, In, Sn, and Te (Galley *et al.* 2007; DeWolfe *et al.* 2024; Li *et al.* 2024; Manor *et al.* 2024; Müller *et al.* 2025).
- Porphyry systems not only provide Cu, Au, and Mo, but are also the main producers of Re, Se and Te, and may eventually be sources of In and Nb (John and Taylor 2016; Müller *et al.* 2025).
- Orogenic Au deposits are the predominant source of Au (Frimmel 2008; Phillips 2013; Lipson 2014; Goldfarb *et al.* 2015; Chugaev 2024) and are commonly enriched in Sb, Ag, Bi, Te, As, W, In, Se and Tl (Goldfarb *et al.* 2016; Müller *et al.* 2025).
- Epithermal deposits have historically been mined for Au, Ag, Cu, Hg, Mn, Pb, Sn, W, and Zn, but may also contain appreciable amounts of As, Bi, In, Sb, Se, Te, and Tl (Goldfarb *et al.* 2016; Müller *et al.* 2025).

The Caledonian-Appalachian orogenic belt extends from Norway, through Britain and Ireland into Newfoundland, maritime Canada and northeastern USA (Fig. 1A). It hosts many deposit types with potential for CRM enrichment. These include VMS (Avoca, Ireland, McConnell *et al.* 1991; Buchans,

Newfoundland, Canada, Piercey *et al.* 2007, 2014, 2023; Sunnhordland, Norway, Strmic Palinkas *et al.* 2024a), orogenic Au (Nugget Pond, Newfoundland, Canada, Honsberger and Bleeker 2018; Honsberger *et al.* 2022; Curraghinalt, Northern Ireland, Rice *et al.* 2016; Lykling, Norway, Strmic Palinkas *et al.* 2024b), epithermal (Hope Brook, Newfoundland, Canada, Dubé *et al.* 1998) and porphyry deposits (Coed-y-Brenin, Wales, Miller *et al.* 1993; Fremstfjell, Norway, Grenne *et al.* 1999; Ackley Granite Suite, Newfoundland, Canada, Kerr *et al.* 2009; Lynch *et al.* 2009). These deposit types commonly occur in arc/backarc packages forming parts of orogenic belts and are found in host rocks of varying geochemical affinity, age and tectonic setting (e.g. Bierlin *et al.* 2009). World-class mineral deposits occur on both sides of the Iapetus Suture Zone in Laurentian and Gondwanan affinity crust (Hollis *et al.* 2014). However, while these deposits are abundant in the Canadian Appalachians (e.g. Piercey *et al.* 2023; Yousefi *et al.* 2024), they are comparatively scarce in the British and Irish Caledonides (Hollis *et al.* 2014, 2016; Rice *et al.* 2018). This is most likely due to a combination of factors, including the lack of exploration and poor preservation of prospective sequences in the Caledonides, as host sequences are temporally and geochemically equivalent (Hollis *et al.* 2014) (Fig. 1B).

The Critical Minerals Intelligence Centre [CMIC] recently evaluated the UK's geology for areas prospective in CRMs (Deady *et al.* 2023) and highlighted the Tyrone Igneous Complex [TIC] of Northern Ireland as a prospective area for several CRMs, notably: Bi, Co, Ga, Ge, In, Mo, Ni, PGEs, Sb, Te and V. Although the TIC has been a target for base and precious metal exploration since the 1970s (Clifford *et al.* 1992; Leyshon and Cazalet 1976; Peatfield 2003), its potential to host VMS mineralisation was recently demonstrated by new geological, geochemical and geophysical data (e.g. Cooper *et al.* 2011; Hollis *et al.* 2012, 2014, 2016). The TIC shares lithological, temporal, and geochemical similarities with central Newfoundland's Annieopsquotch Accretionary Tract (Hollis *et al.* 2012, 2013, in review). This includes the Buchans–Robert's Arm arc system, that contains some of the most metal-rich VMS deposits globally (Piercey 2007). For example, the Buchans deposits produced 16.2 Mt of ore at 14.51% Zn, 7.56% Pb, 1.33% Cu, 126ppm Ag and 1.37ppm Au (Thurlow 2010). Several other styles of mineralisation (including overprinting events) are inferred to occur within the TIC but are poorly constrained due to limited previous study.

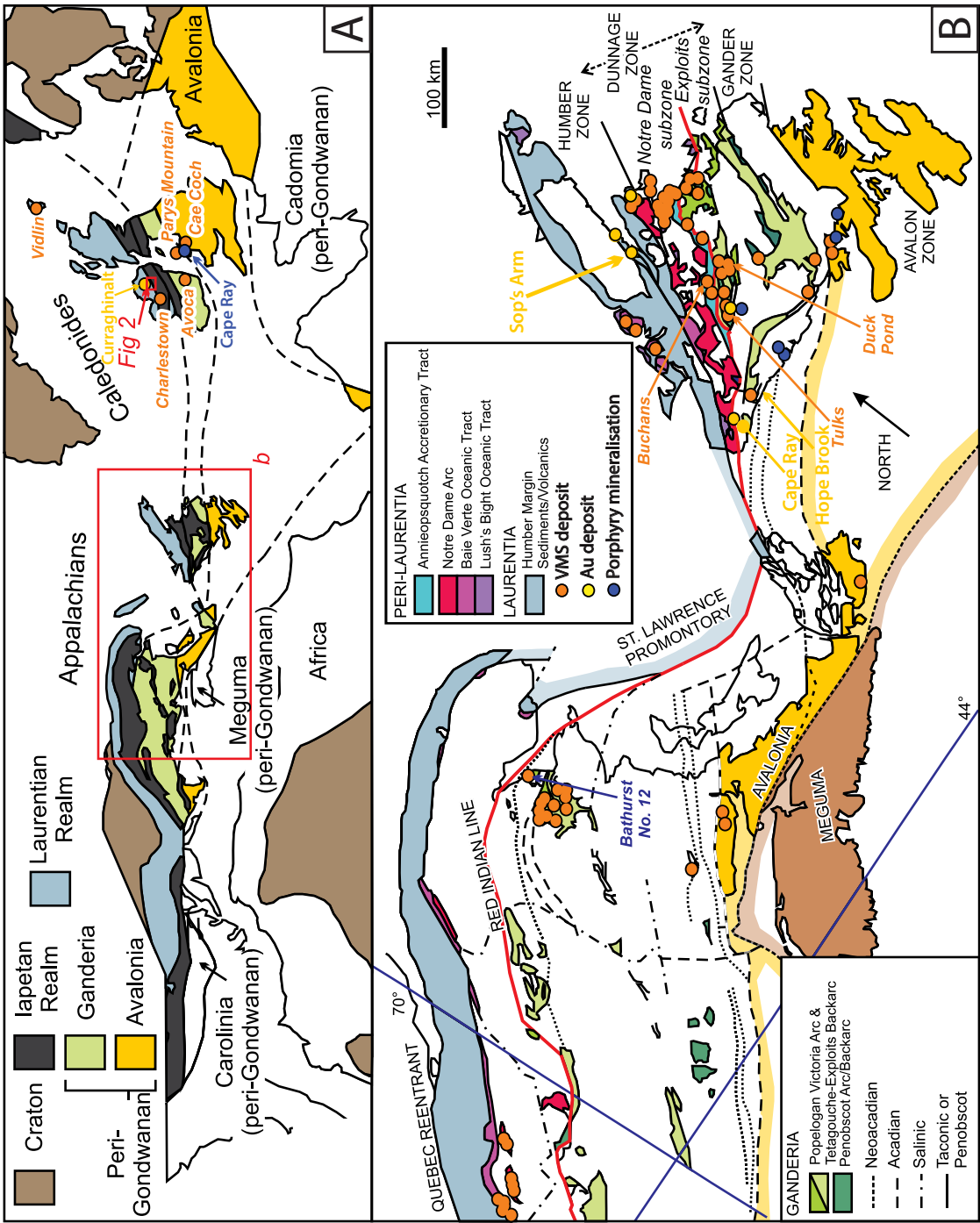


Fig. 1—(A) Restoration of the Early Mesozoic North Atlantic region and Caledonian-Appalachian orogen. (B) Breakdown of peri-Laurentian and peri-Gondwanan zones of Newfoundland with geographical distribution of VMS, Au and porphyry occurrences. Modified after Hollis *et al.* (2012). Au and porphyry occurrences from Honsberger and Bleeker (2018), porphyry mineralisation from Kerr *et al.* (2009).

These include porphyry Cu-Mo, orogenic Au, and epithermal mineralisation. Differences between these occurrences are not well understood but are a crucial part in assessing the potential of the region for the sourcing of metals.

This contribution presents a detailed account of the known mineral occurrences in the TIC, including their sulphide paragenesis, alteration assemblages and host stratigraphies. We aim to better define the potential of the TIC to host CRMs, through an integration of existing data with fieldwork observations, petrographic and whole rock geochemical constraints.

Geological setting

The North American Appalachian Mountain belt and its European counterpart, the Caledonian Mountain belt (Fig. 1A), are the result of the closure of the Iapetus and Rheic oceans during the Paleozoic (van Staal and Barr 2012). Early closure involved the progressive accretion of microcontinental blocks, oceanic tracts and arc-related terranes to the Laurentian margin between the Late Cambrian–Middle Ordovician, which is termed the Grampian-Taconic event (Hollis *et al.* 2012; van Staal and Dewey 2023). Continued ocean closure over the Silurian–Early Devonian resulted in the accretion of Baltica, forming the Scandian Orogeny, which was then followed by the accretion of Gondwanan-affinity microcontinents of Ganderia, Avalonia and Meguma (van Staal *et al.* 1998, 2007; van Staal and Barr 2012; Hollis *et al.* 2014; Shaw *et al.* 2022) (Fig. 1). Within the accreted terranes, arc, backarc and rifting sequences are prospective for VMS, epithermal and porphyry deposits (e.g., Piercey *et al.* 2007; van Staal *et al.* 2007; Piercey and Hinchey 2012; Hollis *et al.* 2014). These various arc and ophiolite sequences were then metamorphosed and deformed through multiple deformation events, making them additionally prospective for vein hosted Au mineralisation (Ritcey *et al.* 1995; Dubé *et al.* 1996; Parnell *et al.* 2000; Ramezani *et al.* 2000; Rice *et al.* 2016; Shaw *et al.* 2022; Hollis *et al.* this volume).

The Tyrone Igneous Complex (c.484–464Ma) is exposed across 350km² of counties Tyrone and Londonderry, Northern Ireland. It occurs in the Midland Valley Terrane and represents one of the largest and youngest Laurentian-affinity arc-ophiolite complexes preserved during the Grampian event (Cooper and Mitchell 2004; Cooper *et al.* 2011; Hollis *et al.* 2012). Older juvenile ophiolitic/arc rocks

(c.510–480Ma) are preserved across the Midland Valley Terrane, within the Ballantrae Igneous Complex, Highland Border Complex, and Shetland ophiolite of Scotland, and the Deer Park Complex and the Lough Nafooy Group of western Ireland (Ryan and Dewey 2011; Molyneux *et al.* 2023; de Sampaio *et al.* 2025). These sequences are all barren of any significant mineralisation. Syncollisional volcanism associated with arc-continent collision is preserved in western Ireland as the Tourmakeady Group (Ryan and Dewey 2011; Molyneux *et al.* 2023), and late continental arc volcanism is preserved in western Ireland in the VMS-bearing Charlestown Group (Herrington *et al.* 2017) and youngest components of the poorly mineralised Ballantrae Igneous Complex (de Sampaio *et al.* 2025).

The Dalradian Supergroup of the Grampian Terrane occurs adjacent to the TIC and represents the deformed passive margin of Laurentia (Cooper and Johnston 2004). It is separated from the TIC by the Omagh Thrust (Fig. 2). The Dalradian Supergroup hosts significant resources of orogenic Au mineralisation at the c.456Ma Curraghinalt deposit (6,099,000 oz contained Au; SRK 2018), and elsewhere across the Grampian Terrane at the c.430–425Ma Cavanacaw deposit (521,109 oz contained Au; Galantas Gold Corporation 2014) and c.410Ma Cononish deposit (266,000 oz contained Au; Scotgold Resources 2015), associated with Grampian and later Scandian orogenic events (Rice *et al.* 2012, 2016; Shaw *et al.* 2022).

The TIC is broadly divisible into the Tyrone Volcanic Group [TVG] (Cooper and Mitchell 2004; Cooper *et al.* 2008; Hollis *et al.* 2012, 2014) and the structurally underlying Tyrone Plutonic Group [TPG] (Hutton *et al.* 1985; Cooper *et al.* 2011; Hollis *et al.* 2013) (Fig. 2). Both the TPG and TVG are intruded by multiple arc-related plutons (Chew *et al.* 2008, Cooper *et al.* 2011). The Tyrone Central Inlier [TCI] is interpreted to be an outriding microcontinental block that is exposed within the central regions of the TIC and represents its underlying metamorphic basement (Chew *et al.* 2008) (Fig. 2).

The TPG is interpreted to represent a c.484–480Ma dismembered suprasubduction zone affinity ophiolite, composed mainly of layered and isotropic gabbros, with lesser sheeted dykes, and rare pillow lavas (Draut *et al.* 2009, Cooper *et al.* 2011, Hollis *et al.* 2013, 2014). The TPG was obducted at c.478Ma onto the TCI and is interpreted in recent tectonic models to form part of the NW-facing juvenile arc system that collided with the Laurentian margin

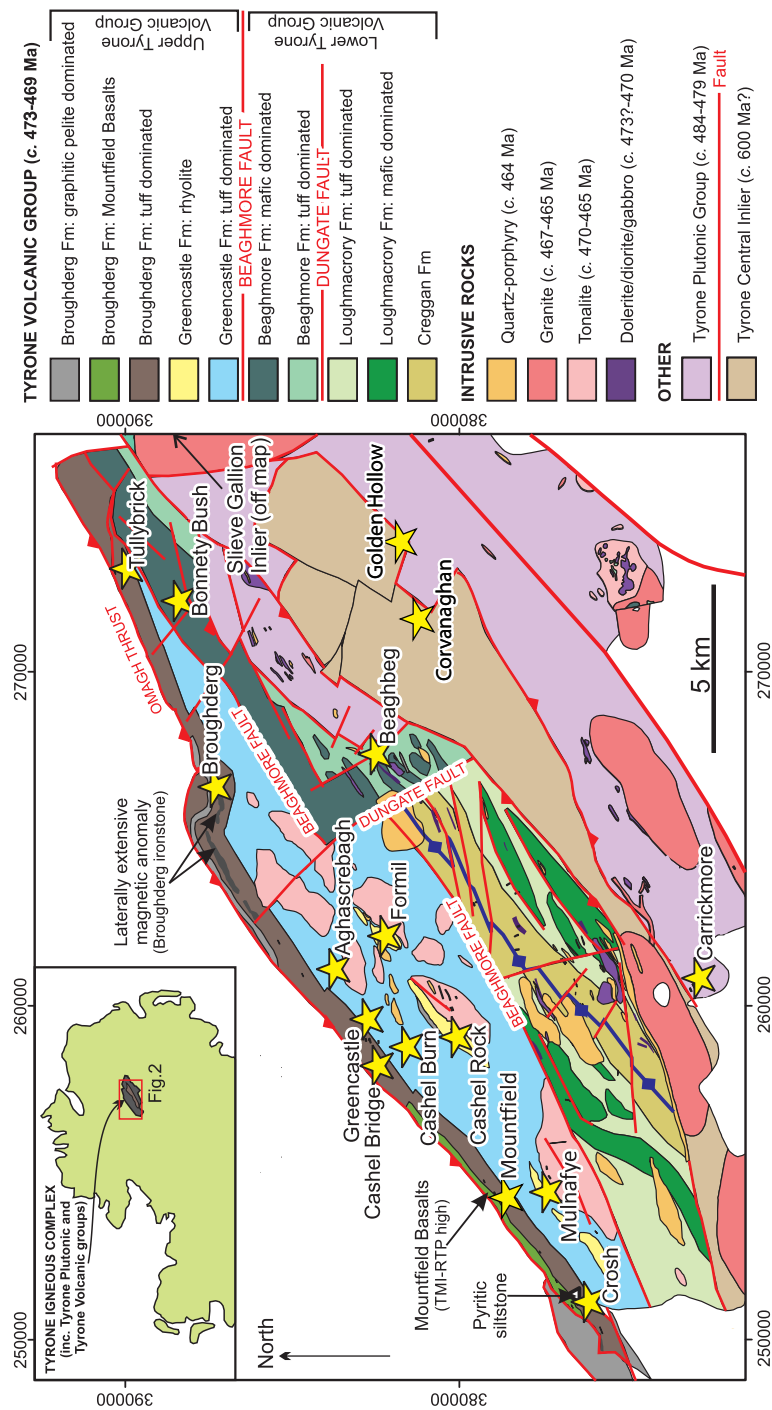


Fig. 2—Map of the Tyrone Igneous Complex, highlighting the various mineralised prospects (yellow stars), along with the boundaries between the Tyrone Plutonic Group, the Tyrone Central Inlier and the Tyrone Volcanic Group. Modified after Hollis *et al.* (2014).

during the Grampian event (Hollis *et al.* in review). Although the TPG is considered to have low potential for VMS mineralisation due to minimal preservation of the upper ophiolite sequence, minor pyrite and chalcopyrite mineralisation has been noted in the sheeted dyke sequences in Carrickmore Quarry (Fig. 2). This is associated with widespread and pervasive clay-rich alteration, a possible siliceous cap gossan (Mawson 2023) and Tellus Cu and Zn soil anomalies that occur in the vicinity (Hollis *et al.* 2016). Further, sulphide and cobalt-bearing gabbroic and ultramafic rocks have been recognised in Orritor Quarry (Mawson 2023) and PGE-enriched sequences in Davagh Forest (Gunn *et al.* 2008).

The TVG represents the remnants of a c.473–469Ma volcanic arc/backarc, subdivided into the basaltic to andesitic dominated Creggan, Loughmacrory and Beaghmore formations, termed the Lower TVG and the andesitic to felsic dominated Greencastle and Broughderg formations, termed the Upper TVG (Hollis *et al.* 2012) (Figs 2–3). Available evidence suggests that the TVG formed within a rifting continental arc/backarc, following the obduction of the TPG onto the TCI (Hollis *et al.* in review). The facing of this arc is unclear, with subduction either occurring outboard of the microcontinental block associated with NW-dipping subduction, or SE-dipping subduction within the seaway (Hollis *et al.* in review). Within the TVG, multiple stratigraphic horizons are considered prospective for VMS mineralisation, due to the occurrence of silica-iron-rich rocks associated with rift-related basalts (typified by Fe-Ti-rich eMORB), and locally intense hydrothermal alteration (Hollis *et al.* 2014, 2015, 2016). Many mineralised occurrences have been identified across the TVG (Hollis *et al.* 2011) but have not been examined in detail. These include those interpreted to be associated with VMS (e.g. Cashel Bridge, Cashel Burn, Aghascrebagh), porphyry Cu (e.g. Formil), and deposits of uncertain origin and timing (e.g. Cashel Rock, Broughderg, Crosh, Tullybrick).

The late continental arc intrusive rocks range in age from c.473–464Ma and include units of gabbro, dolerite, diorite to tonalite, granite and quartz-porphyry (Draut *et al.* 2009; Cooper *et al.* 2008, 2011; Hollis *et al.* 2012). These rocks are interpreted to represent the magmatic plumbing system of the TVG arc lavas that formed in situ upon the obducted TPG (Hollis *et al.* in review). Some of these intrusions are associated with intrusion-related vein hosted Cu-Au mineralisation (e.g. at Mulnafye) (Fig. 2).

The Tyrone Central Inlier [TCI] is composed of sillimanite-grade psammitic and semipelitic

paragneisses (Hartley 1933). Detrital zircon age profiling is consistent with an affinity to the upper Dalradian Supergroup (Chew *et al.* 2008). U-Pb zircon, Ar-Ar and Rb-Sr geochronology from syntectonic leucosomes and cross-cutting pegmatites in the inlier indicate that the deformation and metamorphism of the inlier sedimentary protoliths occurred during the Grampian Orogeny (c.475–465Ma) (Chew *et al.* 2008). These rocks likely formed part of an outboard segment of Laurentia that was detached as a microcontinent block, onto which the TPG was obducted, and TVG later likely formed (Chew *et al.* 2008, Hollis *et al.* 2012, in review). Localised vein-hosted Au mineralisation occurs in the TCI at Corvanaghan Quarry.

Methodology

Samples were collected during field campaigns over several years from mineralised outcrops and from drill core held by Dalradian Gold and the Geological Survey of Northern Ireland. Fieldwork focused on gathering samples for detailed petrographic analysis. Samples were selected based on the intensity and style of alteration, the abundance of sulphides, and using company assays when available. A total of 67 new polished thin sections were produced. The description of polished thin sections focussed on characterising the sulphide and gangue mineralogy to establish paragenetic information. Selected thin sections were further characterised using a Scanning Electron Microscope [SEM] and micro-X-Ray Fluorescence [μXRF].

Micro-analytical characterisation was completed on selected thin sections at the School of Geosciences, University of Edinburgh using Carl Zeiss SIGMA HD VP Field Emission SEM coupled to an Oxford AZtecEnergy Energy dispersive X-ray analysis system [EDS]. A 20kV beam and aperture size of 70μm was used. This provided insight into the microtextural characteristics of the various sulphide assemblages by generating backscatter electron [BSE] images and elemental maps. Point EDS analyses also allowed identification of phases (e.g. xenotime, monazite, electrum) that were too small for standard petrography.

A Bruker M4 μXRF analyser at the Microanalysis Laboratory at Laval University, Canada, was used to produce chemical maps of thin sections and document alteration halos surrounding veins. The data collected allowed for a better understanding of the influence of vein systems on fluid-rock interactions resulting in the formation of sulphides and the

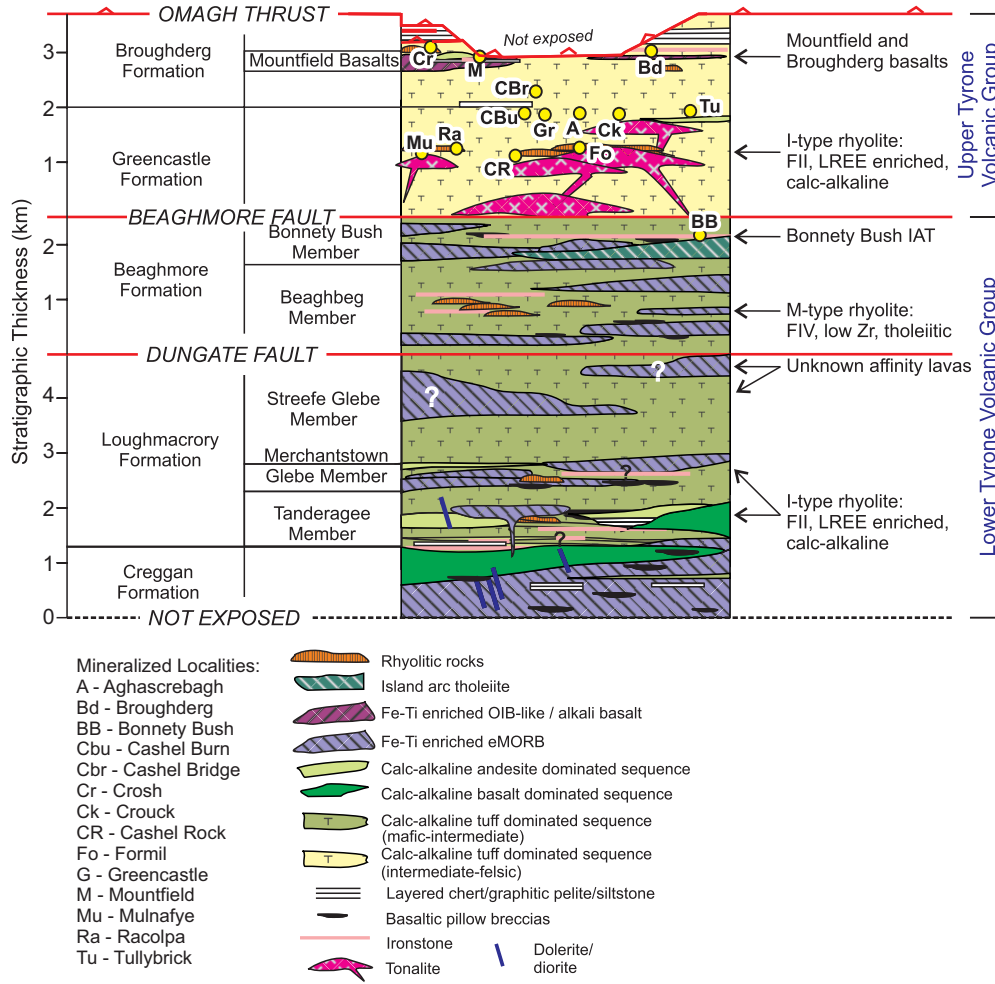


Fig. 3—Simplified stratigraphic section for the Tyrone Volcanic Group (after Hollis *et al.* 2015) showing the geochemical affinities of different units.

concentration of base metals in the different lithologies. Point-by-point μ XRF analyses of the total element spectrum of the sample were collected to produce semi-quantitative chemical composition maps. An acceleration voltage of 50kV, a beam size of 20 μ m and an acquisition time of 10ms were used. The acquired data was subsequently reduced using the Bruker M4 Tornado software.

Bulk geochemistry

Whole rock geochemical data used herein ($n = 3614$) was obtained from drill core and prospecting samples provided by Dalradian Gold Ltd. This includes sample data from Riofinex (1970s), Ennex (1980s), Nickelodeon (1999), Tournigan (2003–08) and Dalradian Gold Ltd. (2010–18). Data from Riofinex and Nickelodeon was treated with caution, as no information exists about their sample

preparation and analytical techniques. For samples from Ennex, little information is available aside from the fact that they were assayed using a mix of wet and fire assay methods. Tournigan samples were analysed for Au using atomic absorption spectroscopy [AAS]. Assay data from Dalradian was produced at ALS laboratories, Loughrea, Ireland using four acid ICP-AES (ALS lab code ME-ICP-61) for multi-element data and fire assays (ALS lab code Au-AA26) for Au. The data presented here focuses on base metals, precious metals and related CRMs to aid our interpretation of mineralisation types (e.g. VMS, porphyry Cu, intrusion-related Au). The data is presented using geometric means to account for sampling bias as some localities only have data from strongly mineralised samples, whereas others include mineralised and unmineralised data from drill core.

Field descriptions and petrography

The TIC has scarce outcrop due to extensive till and peat bog cover, making mineral exploration difficult. Nevertheless, the Tellus soil/stream sampling and geophysical surveys allowed for a much better understanding of the local geology and to generate new mineral exploration targets (Hollis *et al.* 2016; Deady *et al.* 2023). These, combined with historic data, were previously tested by prospecting, revealing numerous mineralised occurrences across the TIC and suggesting that mineral potential exists (Hollis *et al.* 2016) (Figs 4–5). The mineralised occurrences occur at different stratigraphic levels in the TIC and vary in style and proximity to the crustal-scale Omagh thrust (Fig. 2).

The following sections describe the results of this study, which includes field descriptions of mineralised occurrences based on observations made by the authors, integrated with unpublished data, reports and masters theses (e.g. Hilderman 2022; Mawson 2023). This is followed by new petrographic descriptions of the altered host rocks and mineralisation at each locality (Figs 6–10).

Upper Tyrone Volcanic Group

Crosh: Au and VMS targets

Several mineralised occurrences have been noted around the vicinity of Crosh (Fig. 2). Local zones of base-metal and Au mineralisation occur in outcrop within felsic volcanic rocks of the Broughderg Formation (Fig. 4A), many of which are associated with Versatile Time-Domain Electromagnetic [VTEM] resistivity anomalies. Channel sampling around Crosh included silicified tuffs grading 6m at 0.57ppm Au, 18m at 0.42ppm Au and 7.5m at 0.37ppm Au (Tucker 1999). The highest-grade intercept was 24.40ppm Au in prospecting samples. In 2018, ten diamond drillholes were drilled to test fault-hosted Au mineralisation associated with splays along the Omagh Thrust (Dalradian Gold 2019). The geology includes thrust-bound packages of graphitic schist of the Dalradian Supergroup, hydrothermally altered basaltic rocks and tuffs of the Broughderg Formation, and well-bedded sandstones of the Devonian Old Red Sandstone.

Samples from Crosh analysed here are restricted to drill core from the 2018 drilling campaign along the uppermost Broughderg Formation and Omagh Thrust. The sampled volcanic rocks have a quartz-chlorite-sericite-carbonate matrix with low

amounts of quartz/plagioclase phenocrysts that are altered to quartz + sericite. At least two different generations of veins occur, the earliest is composed of quartz-carbonate (ankerite and/or calcite), and crosscut by a second generation of carbonate veining. The whole assemblage is displaced by late chlorite-rich shears. Sulphide assemblages consist of subhedral pyrite $\pm$ arsenopyrite with inclusions of chalcopyrite and sparse sphalerite, and rare molybdenite (Fig. 6A–B). These are generally found associated with early quartz veins and along shears, though small quantities are also observed associated with carbonate alteration/veining and along phenocryst boundaries. Pyrite is the earliest sulphide phase, followed by fracture-filling of chalcopyrite and other base-metal sulphides added to or remobilised in the system. Rare inclusions of molybdenite and nickel-bearing allosclerite also occur within the veins.

Mountfield: VMS target

In the active Mountfield Quarry, basaltic rocks of the Broughderg Formation are exposed along the lower quarry benches (Fig. 2). Previously accessible outcrop on the quarry floor included heavily chlorite-altered and epidote-veined pillow basalts and hyaloclastite with visible disseminated pyrite and chalcopyrite, capped by a haematitic ironstone. Upper quarry benches include a variety of sedimentary rocks, including pyrite-bearing mudstone and shale. A sample of ironstone collected from the floor of Mountfield Quarry (sample MRC1101) is characterised by very low concentrations of base and precious metals (e.g. <0.1ppm Ag, 4ppm Cu, <11ppm Zn) and displays a pronounced negative Eu anomaly.

Samples examined from Mountfield include black shale, basalt and ironstone. The black shale sample is a strongly foliated and sheared schist, with abundant sericite and quartz. Late shears and cracks are filled with graphitic material. The sample is crosscut by multiple generations of veining that are associated with sulphide mineralisation. The earliest vein generations are dominantly quartz-rich and progressively become more carbonate and sulphide-rich in the younger generations. Two main generations of sulphides are recognised, with early anhedral to subhedral pyrite that is mantled by later pyrite $\pm$ chalcopyrite.

Basalts at Mountfield are composed of a fine-grained chlorite-rich groundmass with some hematite that are cross-cut by two sets of veins. Early veins are composed of quartz, whereas the later veins are

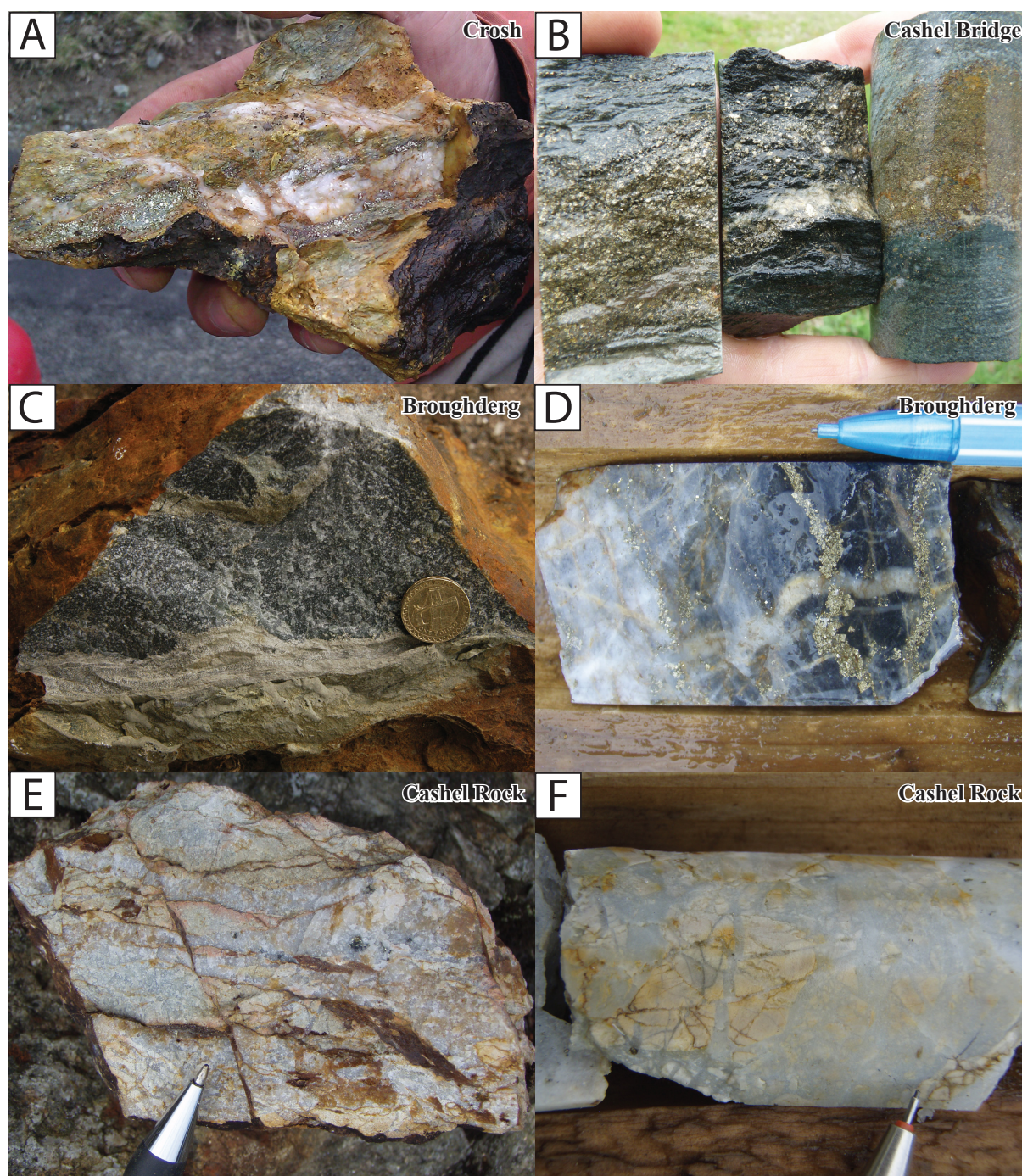


Fig. 4—Photographs of representative samples collected during fieldwork in the Tyrone Igneous Complex. (A) Mineralised felsic grab sample from Crosh. (B) Mineralised chlorite altered tuff from Cashel Bridge. (C) Silicified and mineralised tuff from Broughderg. (D) Pyrite-rich chert core sample from Broughderg. (E) Silicified rhyolite from Cashel Rock. (F) Core sample from Cashel Rock showing strongly silicified rhyolite with hydrothermal brecciation textures.

carbonate, sulphide, and chlorite-rich. Sulphides in the sample are present as anhedral, finely disseminated pyrite with minor chalcopyrite, or as coarse subhedral pyrite with overgrowths and fracture-filling of chalcopyrite.

The ironstone contains multiple generations of quartz/carbonate veins that are cross-cutting a dominantly quartz and hematite-magnetite matrix. Although multiple generations of veining are present, it is devoid of sulphide mineralisation.

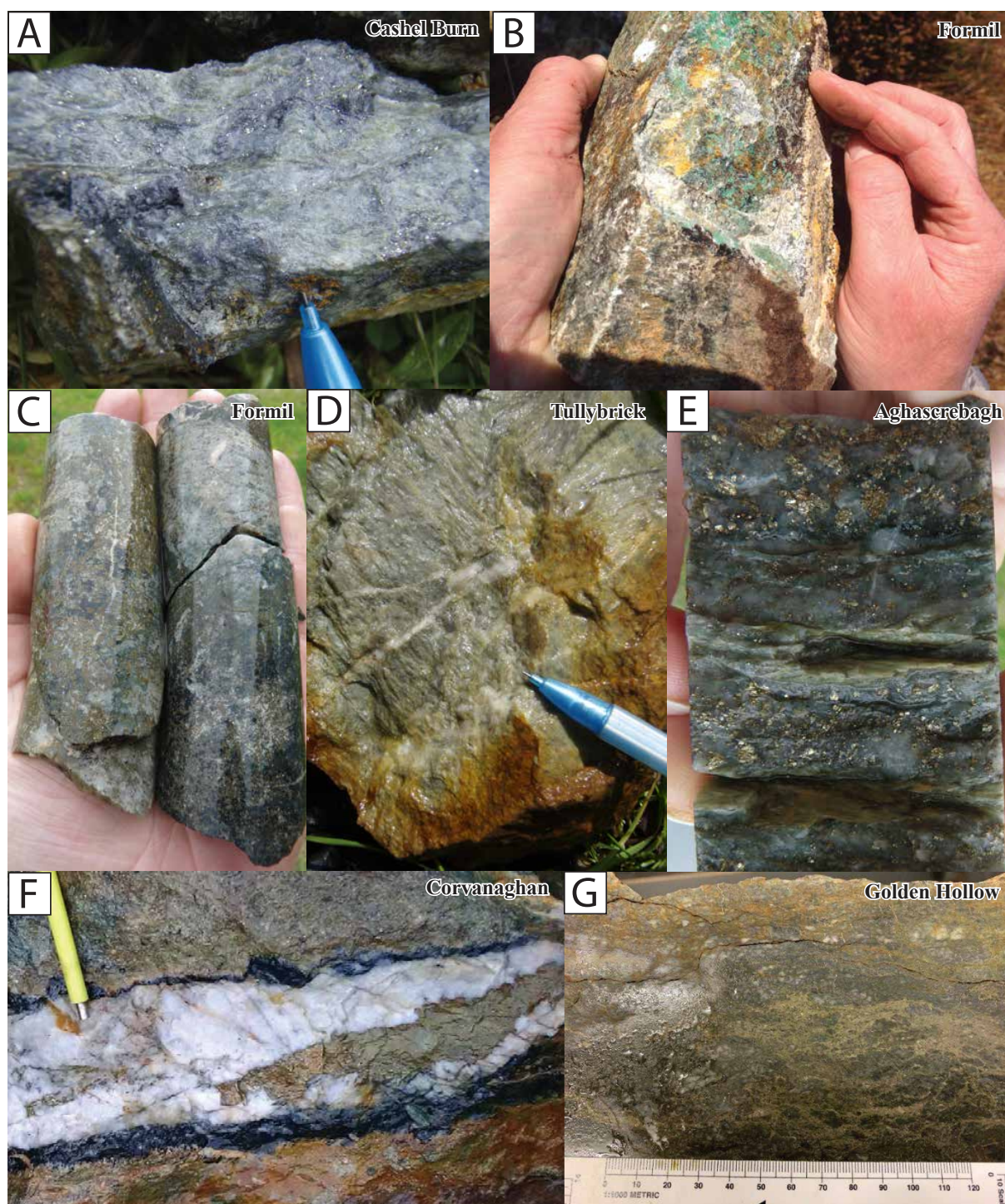


Fig. 5—(A) Mineralised silicified tuff from Cashel Burn. (B) Mineralised rhyolite with malachite staining from Formil. (C) Pyrite-rich core sample from Formil. (D) Strongly altered weakly mineralised tuff from Tullybrick. (E) Mineralised silicified and chlorite altered tuff from Aghascrebagh. (F) “T2 type” vein of quartz-tourmaline with sulphides from Corvanaghan, after Mawson (2023). (G) Slab of mineralised boulder from Golden Hollow, after Mawson (2023).

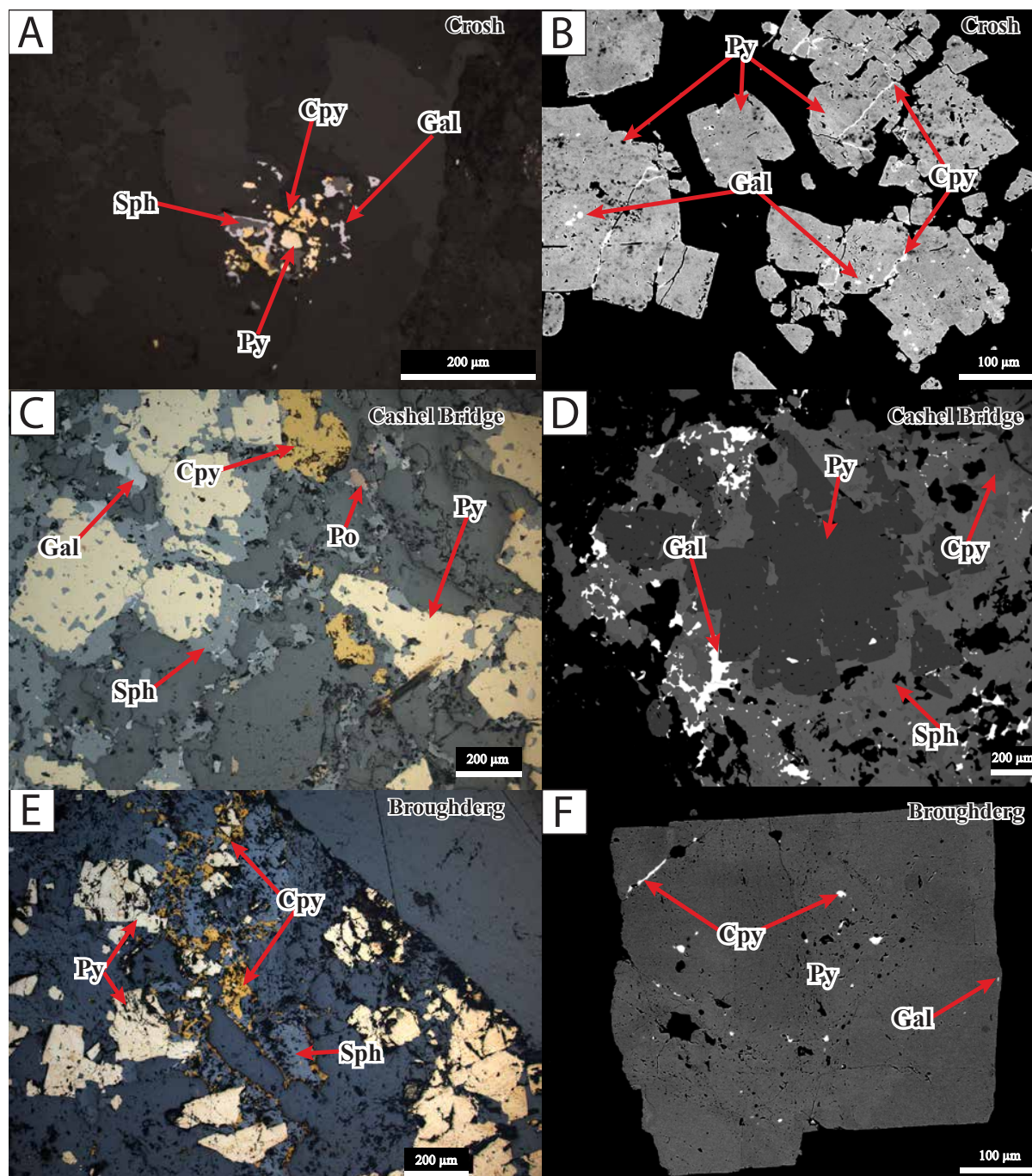


Fig. 6—Photomicrographs and back scatter electron [BSE] images of representative mineralisation in thin sections from Crosh, Cashel Bridge, and Broughderg. (A-B) Pyrite, chalcopyrite, sphalerite and galena at Crosh. Galena and chalcopyrite occur along fracture fill and as inclusions in pyrite. (C-D) Pyrite, chalcopyrite, sphalerite and galena and their textural relationships at Cashel Bridge. (E-F) Pyrite, chalcopyrite, sphalerite and minor galena inclusions in pyrite from Broughderg. Multiple overgrowths can be observed in pyrite in the BSE image. Py, Pyrite; Cpy, Chalcopyrite; Sph, Sphalerite; Gal, Galena.

Cashel Bridge: VMS target

Cashel Bridge is located within the lower part of the Broughderg Formation (Fig. 2), which contains mostly felsic tuffs with lesser chert and argillaceous

sedimentary rocks. Thick sequences of basaltic rocks occur further southeast around Mountfield. The Cashel Bridge target area displays extensive chlorite alteration of tuffs with abundant sericite and carbonate.

Mineralisation occurs predominantly within tuffs and consists of massive pyrite, chalcopyrite, galena and sphalerite (Fig. 4B). Historic prospecting samples include quartz float graded 4.37ppm Au, and chloritic tuff graded 1.06ppm Au, 7.6% Zn, 0.4% Cu, 0.16% Pb (Hollis, 2012a). Although previous drilling was relatively limited (four diamond holes, with three <70m deep), the presence of bedded sulphides (chalcopyrite, sphalerite, galena) in core and the extensive hydrothermal alteration suggest that the area is prospective for VMS mineralisation (Clifford *et al.* 1992). Historic drilling intercepts include 40cm at 3.36% Pb+Zn and 19cm at 1.05% Cu and 2.24ppm Au (Hollis *et al.* 2011).

At Cashel Bridge, tuffs are composed of alternating bands of deformed quartz and sericite/chlorite that are variably cut by two separate vein generations associated with disseminated to semi-massive sulphide mineralisation (Fig. 6C–D). The first is characterised by quartz $\pm$ carbonate, chlorite, sericite and sulphides associated with quartz pressure shadows (subhedral pyrite $\pm$ chalcopyrite, sphalerite, galena, rare pyrrhotite), whereas the second occurs as thin veinlets of quartz/carbonate that are fracture-controlled. At least two generations of pyrite can be distinguished from textural relationships, where earlier, inclusion-rich pyrite displays inclusion-poor rims and the later overgrowths are associated with the wider sulphide assemblage, filling fractures and mantling pyrite grains. Chalcopyrite occurs as discrete grains, but also as chalcopyrite disease (submicron- to micron-sized blebs and irregular inclusions) within sphalerite.

Broughderg: VMS and Au target

The Broughderg target is located within the Broughderg Formation (Fig. 2), and is associated with abundant intensely chlorite-altered, sheared and/or quartz-altered volcanoclastic tuffs, graphitic schist, a prominent chert-ironstone unit, and rare mafic volcanic rocks (Fig. 4C–D). Prospecting sampling of the area identified up to 1.19ppm Au in outcrop, up to 26.75ppm Au in volcanic float, and 2.98ppm Au in chert float (Hollis *et al.* 2011). Historic trenching identified a 1.5m zone of mineralisation grading at 4.36ppm Au and 2.5ppm Ag, while shallow (<20m) drilling intercepted 0.62m at 1.68ppm Au in a blue chert associated with extensive quartz and pyrite veining (Ennex 1986; Hollis *et al.* 2011, 2016). Additional drilling in 2011 tested a large magnetics bullseye anomaly down-dip from the historic Ennex intercept, that was due to the presence of abundance disseminated magnetite (Hollis 2012a).

The trace-element geochemistry of the ironstone displays elevated Ag, As, Au, Cd, Cu, Mo, Pb, Tl and Zn, indicating that this ironstone may be related to VMS mineralisation (Hollis *et al.* 2015, 2016). However, narrow zones of extensive quartz veining associated with broader zones of potassic alteration, that contain abundant pyrite and crosscut the regional foliation, are linked to zones of Au enrichment (e.g. 22cm at 0.66ppm Au, 38cm at 0.5ppm Au).

Samples analysed from Broughderg include ironstones, cherts, feldspar-phyric tuffs and graphitic schist. Ironstones are variably chlorite-altered and have a matrix of variable proportions of quartz and very fine hematite/magnetite. Abundant coarse oxides (magnetite/hematite) are aligned with the foliation. These are crosscut by multiple generations of veining. Early quartz veins that are strongly deformed within the foliation are crosscut by later generations of iron-rich carbonate veins that are variably deformed. Pyrite is very rare and is associated with later carbonate veining.

Cherts display strongly recrystallised coarse-to-fine quartz, with weak sericitic alteration. The graphitic schist is characterised by a very fine quartz-sericite groundmass that is crosscut by graphitic shears. Tuffs similarly comprise of a groundmass of very fine quartz and sericite with a variable abundance of haematite and feldspar phenocrysts that are variably altered to quartz and sericite. These are crosscut by multiple generations of quartz-carbonate (ankerite $\pm$ calcite) veins that are associated with oxides and at least two generations of sulphides (subhedral-euhedral pyrite $\pm$ chalcopyrite, arsenopyrite, galena, molybdenite, sphalerite) and rare inclusions of electrum (Fig. 6E–F).

Cashel Rock: Au target

This occurrence was discovered in the 1980s and is the most extensively studied mineral occurrence in the TVG. The target area is part of the Greencastle Formation (Fig. 2), which contains felsic tuffs, rhyolite flows, and rare sandstone intruded by several sheets of tonalite, lesser diorite and quartz-porphyry. A broad zone of Au mineralisation occurs in outcrop, associated with a crackle-brecciated, quartz-flooded rhyolite that dips $\sim 30^\circ$ W (Hollis 2012a). Historic prospecting samples grade up to 114.8ppm Au (Hollis 2012a). Extensive trenching and shallow diamond drilling (16 holes, mostly <75m length) was completed by Ennex in the 1980s (Ennex 1986). The main zone of quartz flooding averages ~ 2 m in thickness and was traced over a strike length of 200m,

with grades up to 3.63m at 30.51ppm Au (Clifford *et al.* 1992; Hollis 2012a). Additional minor zones of Au mineralisation occur and are associated with base-metal mineralisation (e.g. 1.23m at 1.14% Cu and 1.85% Pb; Hollis 2012a). In the most southerly cross section of drilling the zone of quartz-flooding is underlain by an extensive chloritic stockwork (Hollis 2012a). The second phase of drilling in 2011–12 by Dalradian Gold tested the continuation of the Au-bearing zone of quartz flooding and deeper stockwork further to the southwest (Hollis 2012a).

Cashel Rock samples characterised here are hydrothermally altered and quartz-flooded, flow-banded rhyolites and tuffs. These have a quartz matrix with sparse iron oxides and pervasive sericite alteration (Fig. 4E–F). Areas of intense chlorite alteration are also present in some samples. Variable amounts of sanidine are present but altered into sericite. These are crosscut by multiple generations of quartz $\pm$ chlorite veins that are associated with coarse sulphides (Fig. 7A–D). Subhedral-euhedral pyrite is the most abundant sulphide and is accompanied by variable amounts of fracture filling galena, sphalerite, chalcopyrite and electrum (Fig. 7D). Small grains of Ag-telluride (hessite) are also present (Fig. 8).

Cashel Burn: VMS target

Cashel Burn occurs as an outcrop of strongly foliated, quartz-sericite-pyrite-altered tuff within the upper Greencastle Formation (Figs 2, 5A). It was discovered during a 2011 prospecting campaign and remains untested by drilling (Hollis *et al.* 2016). Outcrop samples have returned values of up to 1.63ppm Au, 14.7ppm Ag, 2.1% Pb and 2.7% Zn (Hollis 2012a).

The Cashel Burn thin sections consist of quartz-altered tuffs with a fine-grained quartz matrix, pervasive sericite alteration and trace fuchsite. Quartz $\pm$ carbonate veins crosscut the matrix and are associated with subhedral, coarse sulphides. The sulphide assemblage includes pyrite, galena, sphalerite and some chalcopyrite. Chalcopyrite is present in sphalerite as chalcopyrite disease. Crystal faces between pyrite, sphalerite and galena, as well as replacement textures, suggest a complex sulphide paragenetic sequence. At least two generations of pyrite are recognised, where pyrite cores are inclusion-rich, whereas the rims are inclusion-poor (Fig. 7E–F).

Formil: porphyry Cu-Mo target

The Formil Cu occurrence is hosted by the Greencastle Formation and is characterised by

flow-banded and brecciated rhyolite, and tuffs that are intruded by large sheets of tonalite and quartz-porphyry (Hollis *et al.* 2012) (Fig. 2). The area was tested by sixteen pits and two trenches by Riofinex in the late 1970s (Riofinex 1974). Several historic drillholes have intercepted minor Cu and Mo mineralisation, where molybdenite is concentrated along shear planes (e.g. H7: 90m at 0.16% Cu, with 1.8m at 0.32% Cu; Leyshon and Cazalet 1976). Four holes were later drilled by Ennex in the 1980s targeting IP anomalies but failed to intercept any significant mineralisation (Ennex 1986). One drill-hole (106-207) encountered 70m of kaolinite altered quartz porphyry (Hollis 2011). More recently discovered outcrops include massive pyrite in quartz-altered tuff with disseminated magnetite (Hollis *et al.* 2016), and extensive exposures of malachite-stained quartz-altered rhyolite cut by thick quartz-chlorite veins containing abundant pyrite and chalcopyrite (Fig. 5B–C). Based on the intense argillic alteration, the widespread disseminated pyrite and Cu mineralisation, along with the presence of Mo, Formil was interpreted to represent a porphyry system (Hollis *et al.* 2011).

Samples from Formil are rhyolitic tuffs and rhyolites that display a fine quartz-sericite matrix with coarser plagioclase porphyroblasts that are variably altered to sericite. These are cross-cut by two sets of quartz $\pm$ (carbonate, chlorite, sericite) veins with well-developed sericite alteration halos and sulphides that are displaced by late shears. The sulphide assemblage is dominated by subhedral-euhedral pyrite with inclusion-rich cores (ilmenite/magnetite, chalcopyrite, molybdenite, galena $\pm$ Bi-Te phases) and inclusion-poor rims mantled by chalcopyrite and molybdenite (Fig. 9A–B). Pyrite grains are also associated with quartz pressure shadows related to post-mineralisation strain. Covellite is associated with the breakdown of chalcopyrite but is interpreted to be related to surface alteration processes.

Mulnafye: intrusion related Au target

The Mulnafye target area occurs in the Greencastle Formation (Fig. 2), where large angular boulders of hydrothermal quartz (to >0.7m in diameter) with pyrite, chalcopyrite and malachite staining occur across several field boundaries and tracks. Historic prospecting has returned values up to 71.5ppm Au, with rare flecks of visible Au identified in several samples (Hollis *et al.* 2011). Although there is no outcrop in the vicinity of mineralisation, the boulders occur along the mapped contact between units of rhyolite and tonalite. Vein material can be seen to

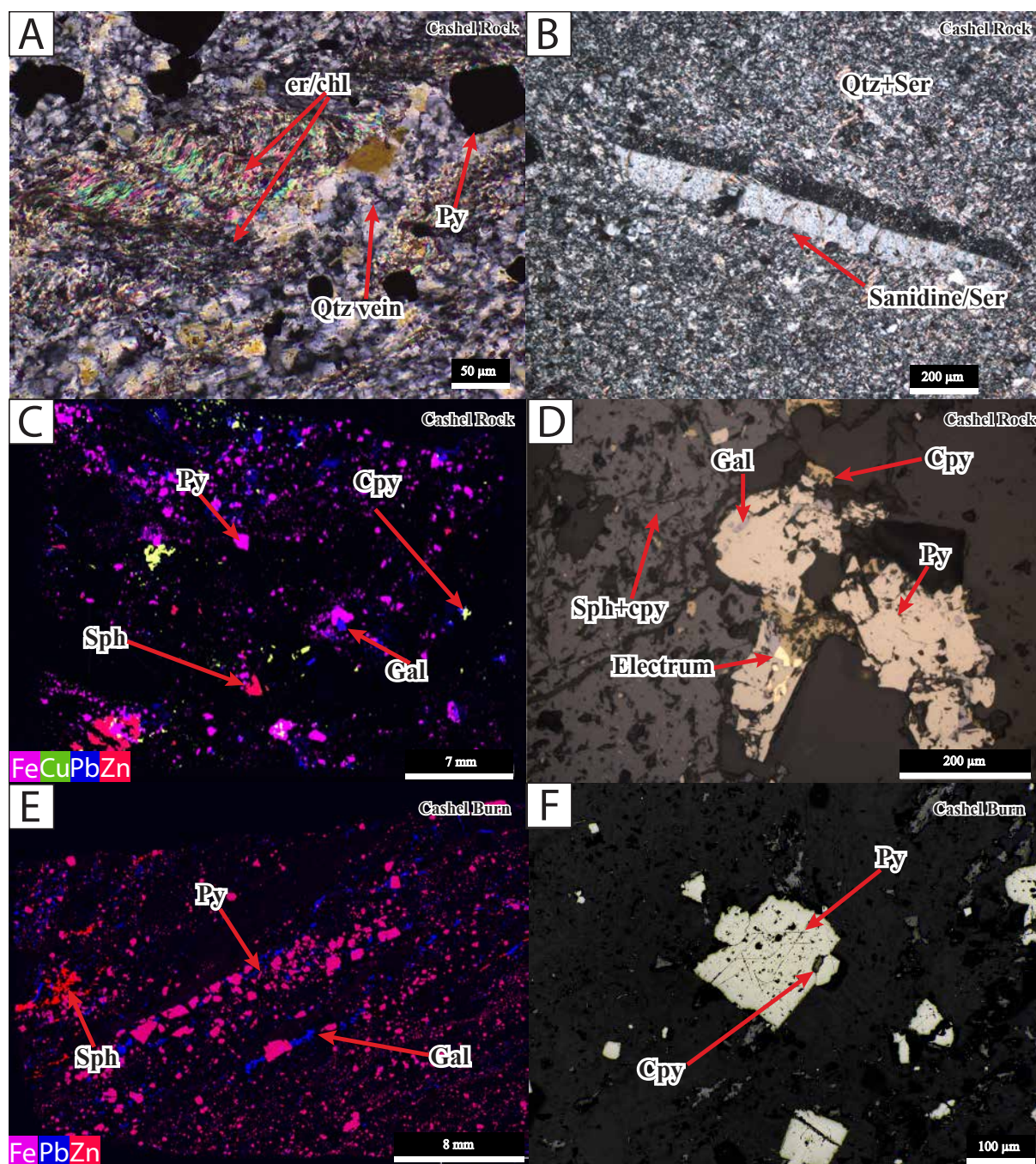


Fig. 7—Photomicrographs of thin sections from Cashel Rock and Cashel Burn. (A) XPL photomicrograph of quartz-sericite alteration and veining. (B) XPL photomicrograph of sanidine partially altered to sericite at Cashel Rock. (C) μ XRF elemental map of Fe, Cu, Pb and Zn, highlighting the various sulphide phases at Cashel Rock. (D) Reflected light photomicrograph showing relationships between sulphide phases and gold at Cashel Rock. (E) μ XRF elemental map of Fe, Pb and Zn highlighting the sulphide phases at Cashel Burn. (F) Reflected light photomicrograph showing chalcopyrite inclusions in pyrite with overgrowths at Cashel Burn. Py, Pyrite; Cpy, Chalcopyrite; Sph, Sphalerite; Gal, Galena; Qtz, Quartz; Ser, Sericite; Chl, Chlorite.

be clearly brecciating tonalite in recovered boulders, and the highest-grade samples occur nearest the mapped contact. Some 700m further northeast, similar quartz-veining occurs in outcrop as thin veins

cutting tonalite and is associated with pyrite-chalcopyrite mineralisation in the stratigraphically overlying, hydrothermally altered felsic volcanic rocks. Historic deep overburden samples are anomalous in

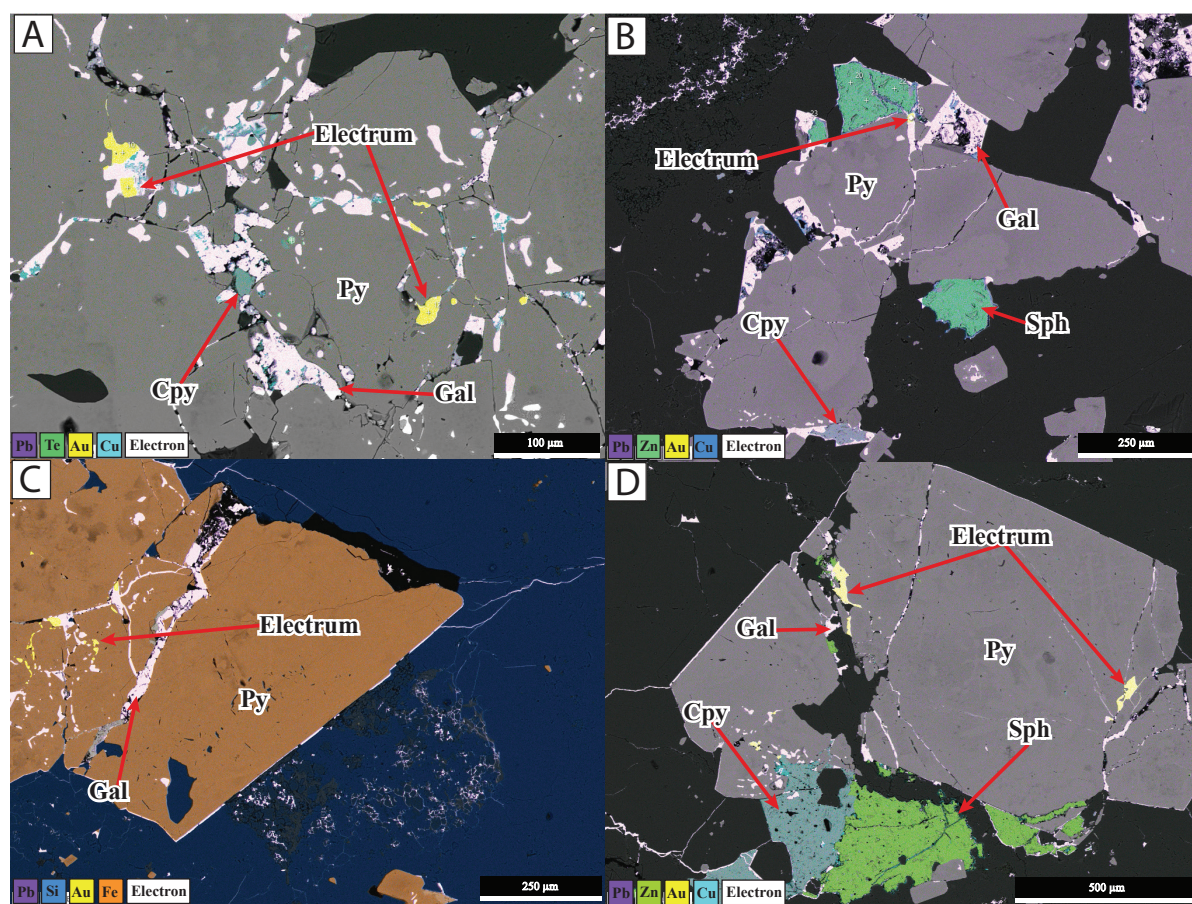


Fig. 8—(A–D) SEM back scatter electron [BSE] images with elemental mapping of sulphides and gold from Cashel Rock. Gold is found in pyrite fractures, along with galena, chalcopyrite, sphalerite and Ag-tellurides. Py, Pyrite; Cpy, Chalcopyrite; Sph, Sphalerite; Gal, Galena.

Au (to 32ppm) over the Mulnafye target area, and 2012 soil sampling revealed an area of high Au (>23 ppb, 95% percentile; to 400 ppb maximum) along the mapped lithological rhyolite-tonalite contact (Hollis 2012b).

Quartz vein material from Mulnafye is dominated by a sulphide assemblage of coarse chalcopyrite (Fig. 9C–D). It also contains sparse tourmaline, mm-scale Sr-bearing barite and shows significant quartz recrystallisation and internal strain. Chalcopyrite contains rare inclusions of galena and displays secondary surface alteration into covellite and malachite associated with Bi-Te and Ag-Cl phases.

Tullybrick: VMS and Au target

Tullybrick is hosted within the uppermost Greencastle Formation and is characterised by intermediate to felsic tuffs with minor occurrences of rhyolite (Figs 2, 5D). At Tullybrick, Au mineralisation occurs in association with chlorite-altered, bleached

and sericitised intermediate crystal tuffs with zones of up to 5% pyrite and minor fuchsite (Clifford *et al.* 1992). Clifford *et al.* (1992) report assay values of silicified zones up to 2.78ppm Au. Grades in float samples are slightly lower, with chert with pyrite assaying 1.8ppm Au and chloritic tuff with disseminated pyrite returning values up to 1.76ppm Au (Hollis *et al.* 2011). Deep overburden samples are also anomalous in Au, Cu, Zn and Pb, and sections of bedrock, and stream sections are associated with base-metal mineralisation (Hollis *et al.* 2011). Diamond drilling in 2011 tested the southernmost of two nearby induced polarisation [IP] anomalies and revealed extensive chloritic and sericitic hydrothermal alteration associated with abundant disseminated pyrite, though no significant Au was identified. The northernmost IP anomaly remains untested (Hollis 2012a).

The Tullybrick samples analysed here are foliated tuffs that are strongly sericite- and carbonate-altered. The matrix varies between sericite, quartz and

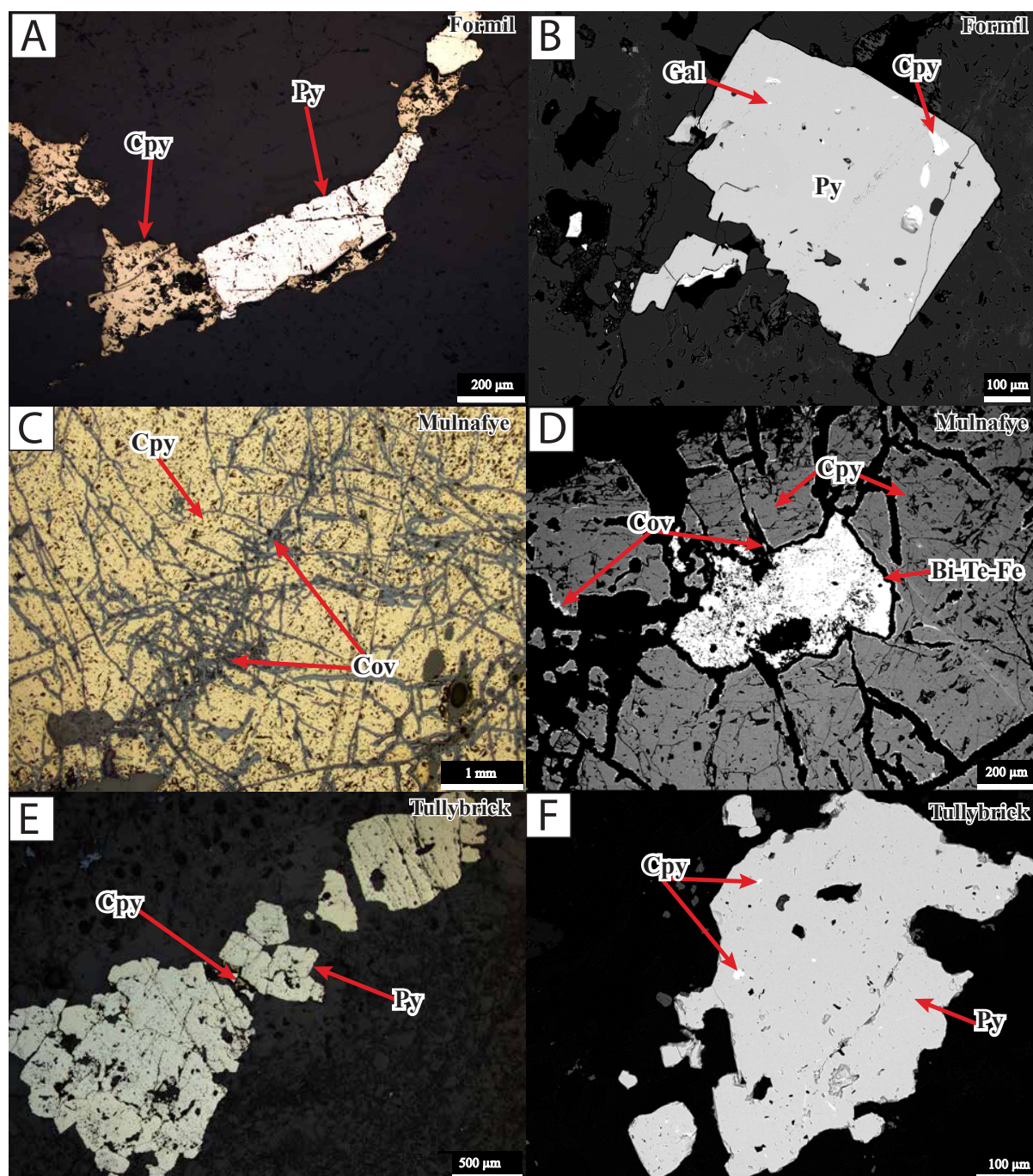


Fig. 9—Photomicrographs and back scatter electron [BSE] images of representative mineralisation in thin sections from Formil, Mulnafye, and Tullybrick. (A-B) Pyrite, chalcopyrite and galena from Formil. (C-D) Chalcopyrite with secondary alteration into covellite and Bi-Te-Fe phases at Mulnafye. (E-F) Pyrite with chalcopyrite inclusions at Tullybrick. Py, Pyrite; Cpy, Chalcopyrite; Gal, Galena; Cov, Covellite.

carbonate (ankerite and/or calcite) dominated, with minor chlorite. Some relict plagioclase phenocrysts occur but are strongly altered to sericite and quartz. Veining is not abundant, but when observed is mostly quartz $\pm$ carbonate that is associated with

sulphides. The latter comprise of subhedral pyrite with small inclusions of chalcopyrite and rare galena (Fig. 9E–F). At least two generations of pyrite are distinguished by their textural relationships, with inclusion-rich cores and inclusion-poor rims.

Chalcopyrite formed after the initial pyrite growth, as it occurs along fractures in the early pyrite.

Aghascrebagh-Crouck: VMS target

The Aghascrebagh-Crouck target area is hosted in the upper part of the Greencastle Formation and the lower part of the Broughderg Formation (Fig. 2). Six shallow diamond holes were drilled by Ennex (all <100m deep), with the best intercept being 52cm at 1.9% Pb+Zn and 0.48ppm Au (Hollis *et al.* 2011). Prospecting samples of mineralised volcanic float have returned assay values of 5.94ppm Au, 4.0% Pb, and 8.8% Zn in different samples (Hollis *et al.* 2011). Due to the widespread intense hydrothermal alteration and abundance of mineralised float, the area was previously deemed prospective for VMS mineralisation (Ennex 1986; Clifford *et al.* 1992; Hollis *et al.* 2014, 2016).

At Aghascrebagh, strongly foliated quartz-sericite tuffs contain foliation-subparallel quartz veins related to a well-developed carbonate+chlorite+sericite+sulphide alteration halo and are crosscut by late shears (Fig. 5E). Sulphides, comprising of subhedral to euhedral pyrite with clear early cores and later overgrowths associated with galena, sphalerite and chalcopyrite, display quartz pressure shadows and are spatially related to patches of chlorite (Fig. 10A).

Lower Tyrone Volcanic Group

Bonnety Bush: VMS target

The Bonnety Bush target area is in the Beaghmore Formation of the Tyrone Volcanic Group (Fig. 2) that is locally dominated by basalts of both tholeiitic and eMORB–OIB affinity and basaltic agglomerate, overlain by jasper/ironstone and silicified chloritic volcanoclastic tuff of andesitic composition. Due to thick cover sequences of peat and till, exposure is extremely poor apart from an outcrop of variably mineralised jasper/ironstone. Deep overburden geochemistry samples assay up to 960ppm Zn, 750ppm Pb, 365ppm Cu and 77ppb Au (Hollis *et al.* 2011). Few prospecting samples have been collected in this area, though one sample of tuff float with pyrite and galena assayed 2.98ppm Au (Hollis *et al.* 2011). Float samples of magnetite-bearing ironstone with stringer pyrite has assayed 4.54ppm Au (Hollis *et al.* 2011). Ironstones at Bonnety Bush are quartz-rich with magnetite and ilmenite, are brecciated and display pervasive chlorite alteration (see Hollis *et al.* 2015), where massive chlorite is associated with

sulphides between clasts. Sulphides include at least two generations of subhedral to euhedral pyrite that contains small inclusions of chalcopyrite, Ag-Te-Bi-bearing galena, pyrrhotite and sphalerite. Covellite is also present, but is interpreted to be a secondary surface alteration of chalcopyrite. The different pyrite generations are distinguished by their core to rim relationships, where cores are inclusion-rich and rims are not (Fig. 10B–C).

Tyrone Plutonic Group

Carrickmore Quarry: VMS target

In Carrickmore Quarry vertical sheeted dolerite dykes and medium-grained gabbros of the Tyrone Plutonic Group are exposed (Fig. 2). Areas of quartz-epidote alteration and minor chlorite alteration are common. Pyrite and chalcopyrite occur as minor disseminations and stringers within the mafic rocks, and within late fractures associated with bornite, malachite and azurite. Widespread and pervasive alteration, to a clay-rich assemblage of chlorite and possible smectite, is present in a western section of the quarry (Mawson 2023). A 30cm quartz-rich layer containing iron hydroxide staining on weathered surfaces was interpreted by Mawson (2023) as a cap gossan and overlies the altered section.

Tyrone Central Inlier

Corvanaghan Quarry: vein-hosted base- and precious-metal target

Corvanaghan Quarry is located within the high-grade metasedimentary rocks of the Tyrone Central Inlier (Fig. 2). Two types of quartz veining are described by Mawson (2023), termed T1 and T2. Relative ages are not clear through field relationships. Type 1 quartz-sulphide veins occur with a pinch and swell geometry that brecciate the local paragneisses and are orientated NW–SE (Mawson 2023). A separate generation (T2, Fig. 5F) are hosted by persistent, planar, N–S orientated fractures steeply dipping to the east and containing en-échelon sulphide textures with quartz and tourmaline (Mawson 2023). Both veins contain anomalous Co, Bi and Ni, with T1 veins recording higher values (up to 1999ppm Co, 1670ppm Ni, 2110ppm Bi in separate samples) (Mawson 2023). Gold grades are low (<0.1ppm Au) in analysed samples.

At Corvanaghan, quartz-altered schists are characterised by a strongly-foliated quartz-sericite matrix with minor chlorite and biotite and accessory

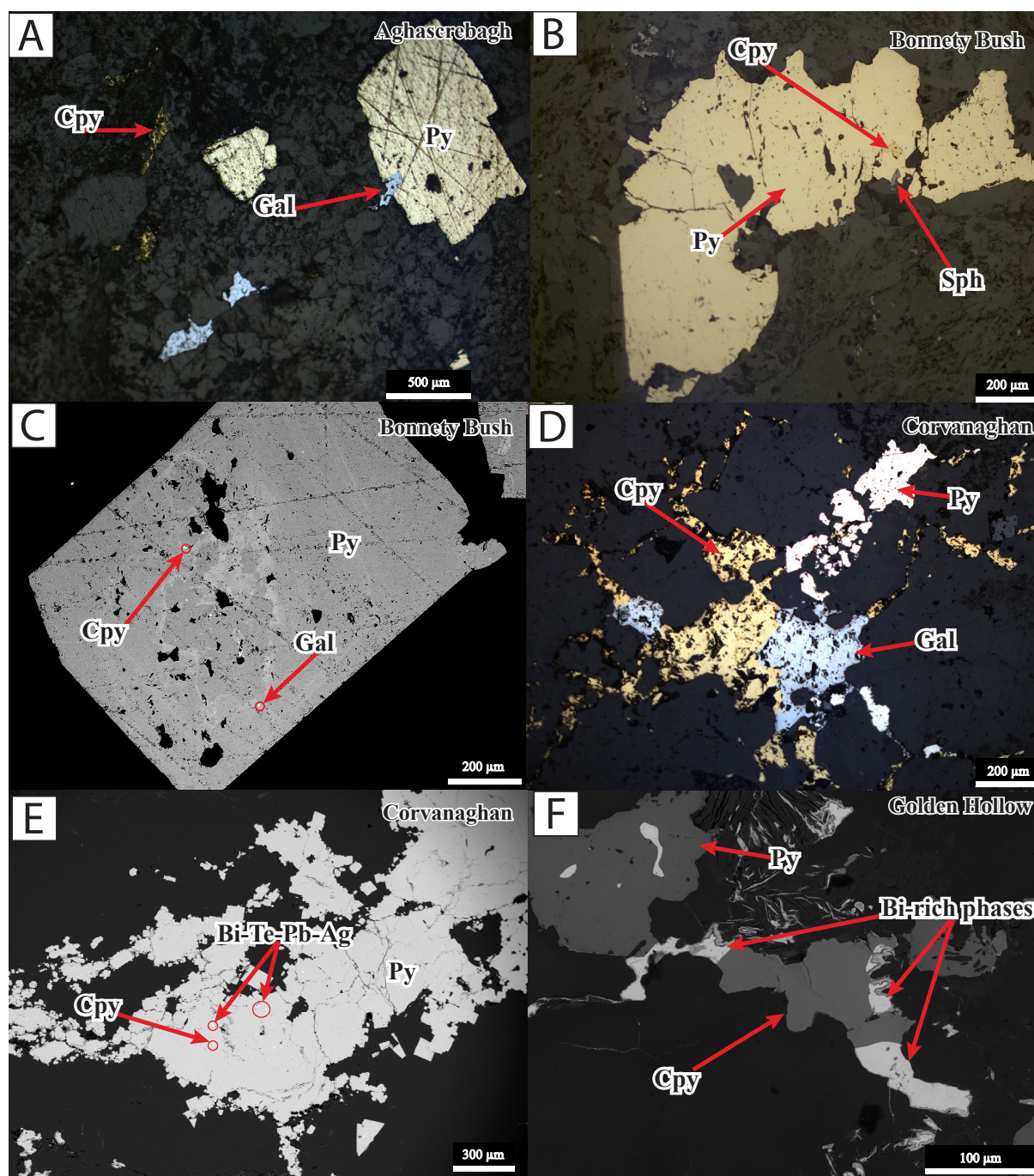


Fig. 10—Photomicrographs and back scatter electron [BSE] images of representative mineralisation in thin section samples from Aghascrebagh, Bonnetty Bush, Corvanaghan and Golden Hollow. (A) Reflected light photomicrograph of pyrite, chalcopyrite and galena and their relationships from Aghascrebagh. (B-C) Reflected light photomicrographs and BSE image of pyrite with overgrowths, chalcopyrite, sphalerite and galena occurrences and relationships at Bonnetty Bush. (D-E) Pyrite, chalcopyrite and galena sulphide assemblage with Bi-Te-Pb-Ag and chalcopyrite inclusions in pyrite at Corvanaghan. (F) BSE image of pyrite, chalcopyrite and bismuth-rich phases at Golden Hollow. Py, Pyrite; Cpy, Chalcopyrite; Sph, Sphalerite; Gal, Galena.

ilmenite, rutile, hematite and ?hinsdalite. In thin section, two quartz vein generations are recognised, the first one is strongly deformed within the foliation,

whereas the second one is associated with a sericite alteration halo, chlorite, sulphides and rare scheelite and barite. Sulphides are dominated by anhedral to

subhedral pyrite with overgrowths, sparse pyrrhotite inclusions, fracture-filling by chalcopyrite and Ag-bearing galena, S-Bi-Te phases and rare arsenopyrite (Fig. 10D–E). The S-Bi-Te phases are micron-scale and are tentatively interpreted to be native Bi, bismuthinite and bismuth tellurides.

Golden Hollow: Cu-Au-Bi target

Golden Hollow is located approximately 2km ESE from Corvanaghan Quarry, on the easternmost edge of the Tyrone Central Inlier, where it is in faulted contact with the Tyrone Plutonic Group (Fig. 2). A deep red weathered and oxidised boulder of 30% pyrite-veined and quartz-flooded material was discovered in a stream at this prospect (Fig. 5G). Shackleton Resources' whole rock geochemistry gives maximum values of 2.7% Cu, 4,520ppm Bi, 61ppm Ag, and 0.33ppm Au (Mawson 2023). Other base metal contents are low (e.g. 48ppm Zn, 44ppm Pb) (Mawson 2023). The protolith of the sample is unknown due to the extensive alteration and mineralisation present.

The boulder from Golden Hollow contains aggregates of euhedral to subhedral pyrite with a stockwork-like texture, surrounded by abundant hydrothermal quartz with lesser chlorite and muscovite. Pyrite, chalcopyrite, bismuthinite, and an unknown Bi-Cu sulphosalt, all occur interstitial to the quartz, and along the cleavage planes of micas (Fig. 10F).

Bulk geochemistry

Bulk geochemistry results further highlight key differences between mineralisation types found in the TIC (Table 1, Fig. 11). Grouped by target type, VMS samples (e.g. Cashel Bridge, Cashel Burn, Aghascrebagh) have the highest geometric average concentration of As, Au, Pb, Zn and S content of the studied localities, with Cu grades comparable to porphyry-style mineralisation at Formil. The VMS samples also show generally low Hg and W concentrations compared to the other groups. Gold targets (e.g. Crosh, Broughderg, Tullybrick, Cashel Rock) have the highest geometric mean concentrations of Sb, Mn, W and Hg, the highest maximum concentrations of Au, Hg and Ag, and have low base-metal contents and Bi. The porphyry target Formil has the highest geometric average concentration of Mo, high concentrations of Cu, anomalous W, and low concentrations of As, Pb, Zn, Mn, Sb, Ni and Te. The intrusion-related deposits group (i.e. Golden

Hollow, Corvanaghan, Mulnafye) comprises of only four samples, which are highly mineralised, skewing the data. However, they contain extremely elevated Co-Bi-Te concentrations relative to the other occurrences, have elevated Cu and Ni, and low concentrations of Zn, Pb, Hg and Mn compared to other groups. Some of the individual occurrences are notable not only within their respective groups, but also from the whole dataset. Notably, Cashel Burn by far has the highest geometric average concentration of combined base metals, whereas Cashel Rock has the highest maximum concentration of Au, Ag and As. Furthermore, Crosh has highly anomalous Sb contents, while Broughderg and Tullybrick are W-rich.

Discussion of mineralisation types and their potential by locality

The various mineralised occurrences described in this contribution are discussed here as a function of their tectonic setting and interpreted mineralisation style and deposit type.

VMS style mineralisation

VMS prospects can be found in both the ophiolitic *c.*484–480Ma Tyrone Plutonic Group and the overlying younger overlying *c.*473–469Ma Tyrone Volcanic Group. Within the ophiolite (i.e. TPG), minor occurrences of VMS-style mineralisation are found at Carrickmore where disseminated and stringer-style Cu sulphides are recorded (Fig. 2). These would be expected to resemble Cyprus-type (i.e. mafic) VMS deposits, which are usually Cu-rich but can also produce Zn, Au and occasionally Co-Ni (Galley *et al.* 2007; Piercey *et al.* 2023). However, VMS mineralisation is rare in the TPG due to a lack of preservation of the upper part of the ophiolite sequence (Hollis *et al.* 2014). Pillow lavas are rare in the TPG and only present as roof pendants in an intrusion of tonalite at Craigballyharky (Cooper *et al.* 2011; Hollis *et al.* 2013), so minor VMS mineralisation would be limited to these sequences and parts of the upper sheeted dyke complex.

In the TVG, known VMS-style occurrences are found in the Greencastle and Broughderg formations at Cashel Bridge, Cashel Burn, Mountfield and Aghascrebagh, in addition to at Bonnetty Bush in the Beaghmore Formation (Hollis *et al.* 2014) (Fig. 2). Whereas the Greencastle and Broughderg formations are dominated by felsic volcanic/volcaniclastic rocks (with lesser basalt around Mountfield), the Beaghmore formation is dominated by mafic

Table 1—Geochemical data compilation (As, Sb, Pb, Mo, Te, Zn, Au, Mn, Bi, Cu, Co, Ni, Hg, W, Ag) of the studied occurrences found in the Tyrone Igneous Complex. VMS, Au occurrences and porphyry data from Dalradian Gold Ltd., intrusion-related data from Mawson (2023).

Occurrence	As (ppm)			Sb (ppm)			Pb (ppm)			Mo (ppm)			Te (ppm)		
	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max
Cashel Burn (n = 29)	139	37	0.0	0	7736	1107	3.5	3.4	5.4	5.4					
Cashel Bridge (n = 184)	521	10	11.9	1.3	10300	98	33.1	1.1	2.3	0.1					
Aghascrebagh (n = 227)	16800	1	2.5	0.4	40000	120	19.2	1.2	10.7	0.7					
All VMS	16800	7	11.9	0.8	40000	235	33.1	1.6	10.7	0.8					
Tullybrick (n = 152)	39	3	2.5	2.5	25	3	5.1	0.7	10.5	2.7					
Crosh (n = 1411)	7290	13	288.0	4.9	937	5	291.1	1.0	2.5	2.5					
Cashel Rock (n = 852)	11500	3	5.2	2.5	42400	20	15.0	0.8	11.0	2.8					
Broughderg (n = 323)	90	5	6.1	2.5	10620	5	365.4	2.2	13.9	2.8					
All Au occurrences	11500	6	288.0	3.1	42400	8	365.4	1.2	13.9	2.7					
Porphyry: Formil (n = 432)	25	1	7.0	0.5	6700	14	915.0	11.4	7.0	0.2					
Corvanaghan (n = 3)	45	7	2.2	1.5	463	144	3.0	0.6	52.6	29.7					
Golden Hollow (n = 1)	28	28	3.3	3.3	44	44	4.4	4.4	39.5	39.5					
All intrusion related	45	14	3.3	2.2	463	79	4.4	1.7	52.6	34.3					

Occurrence	Zn (ppm)			Au (ppm)			Mn (ppm)			Bi (ppm)			Cu (ppm)		
	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max
Cashel Burn (n = 29)	76000	8919	4.4	0.4	2556	392	6.0	6.0	4000	179					
Cashel Bridge (n = 184)	49700	314	3.0	0.1	4070	1342	11.0	1.2	10500	132					
Aghascrebagh (n = 227)	>100000	176	5.9	0.1	17001	292	9.9	0.4	35800	82					
All VMS	>100000	790	5.9	0.1	17001	536	11.0	1.4	35800	125					
Tullybrick (n = 152)	110	37	1.9	0.0	2324	847	3.4	0.1	552	23					
Crosh (n = 1411)	12500	75	24.4	0.0	9490	1168	20.5	0.1	4380	40					
Cashel Rock (n = 852)	2941	56	114.8	0.0	2440	340	4.8	0.0	13500	10					
Broughderg (n = 323)	408	68	3.0	0.0	31537	1210	21.6	0.3	1993	34					
All Au occurrences	12500	59	114.8	0.0	31537	891	21.6	0.1	13500	27					

continued

Table 1—(Continued)

Occurrence	Zn (ppm)		Au (ppm)		Mn (ppm)		Bi (ppm)		Cu (ppm)	
	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean
Porphyry: Formil (n = 432)	17500	31	1.5	0.0	2725	191	15.4	0.7	4800	123
Corvanaghan (n = 3)	193	35	0.1	0.0	761	201	2110	563	265	66
Golden Hollow (n = 1)	48	48	0.3	0.3	90	90	4520	4520	27000	27000
All intrusion related	193	41	0.3	0.1	761	134	4520	1595	27000	1338
Occurrence	Co (ppm)		Ni (ppm)		Hg (ppm)		W (ppm)		Ag (ppm)	
	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean	Max	Geo Mean
Cashel Burn (n = 29)	17	13	40	24	BDL	BDL	BDL	BDL	64	BDL
Cashel Bridge (n = 184)	53	19	79	29	BDL	BDL	15	2.5	62.9	BDL
Aghascrebagh (n = 227)	107	11	83	20	0.5	0.5	6	2.6	106.2	BDL
All VMS	107	14	83	24	0.5	N/A	15	2.5	106.2	N/A
Tullybrick (n = 152)	71	13	107	34	1.9	0.5	7.5	2.5	1.4	BDL
Crosh (n = 1411)	203	26	2122	38	2.3	0.6	63.0	6.0	13.7	BDL
Cashel Rock (n = 852)	19	2	73	2	1.0	0.5	34.0	3.6	122.4	BDL
Broughderg (n = 323)	168	19	866	23	2.0	0.5	120.4	5.7	2.4	BDL
All Au occurrences	203	11	2122	16	2.3	0.5	120.4	4.2	122.4	BDL
Porphyry: Formil (n = 432)	38	12	85	5	0.5	0.5	17.5	3.7	20.6	N/A
Corvanaghan (n = 3)	1200	137	181	88	BDL	BDL	5.4	1.7	11.2	5.0
Golden Hollow (n = 1)	153	153	43	43	BDL	BDL	5.3	5.3	61.5	61.5
All intrusion related	1200	145	181	62	N/A	N/A	5.4	3	61.5	17.6

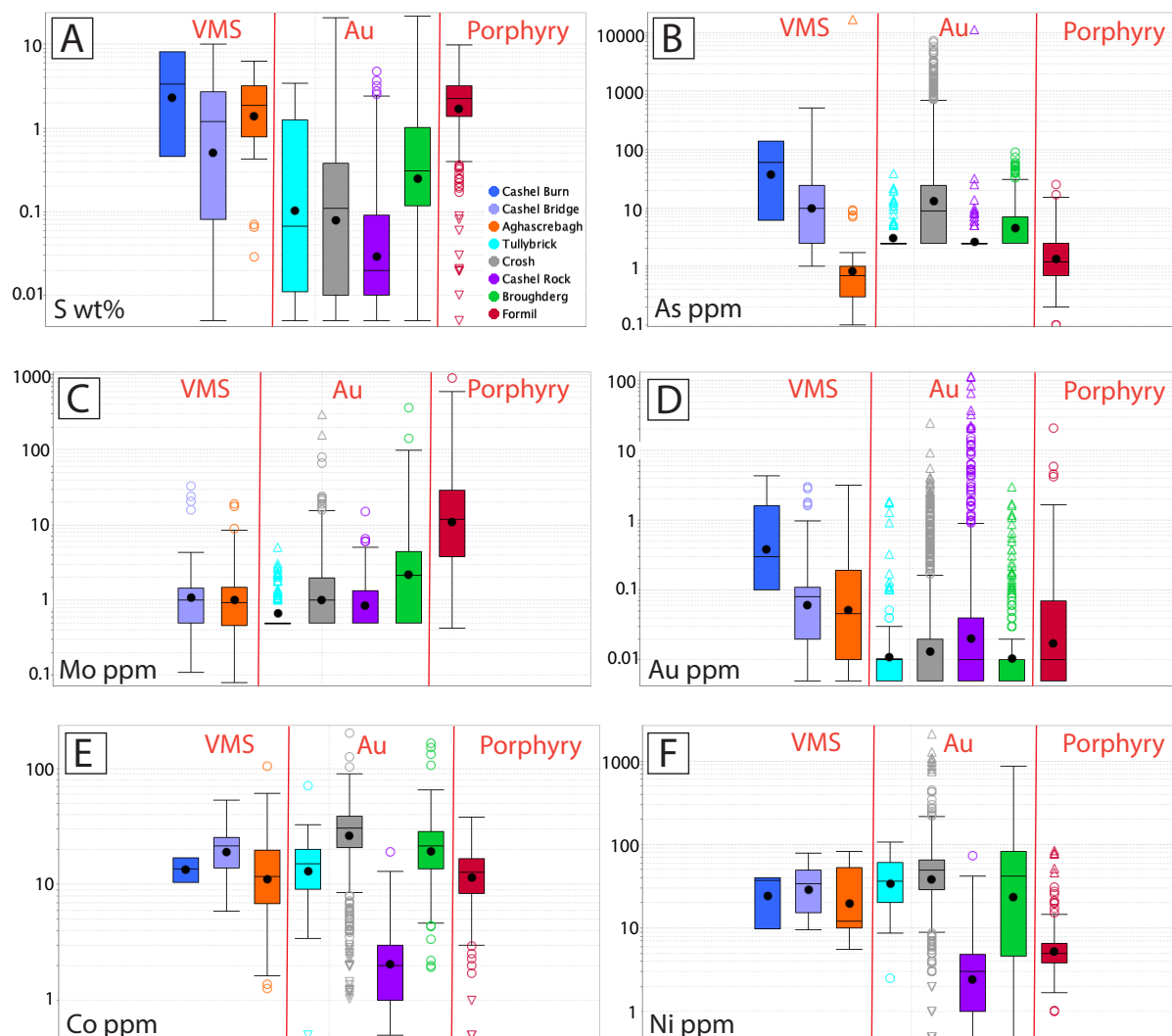


Fig. 11—Box plots of a geochemical compilation (from Dalradian Resources Ltd.) of mineralised occurrences hosted in the TIC for sulphur, arsenic, molybdenum, gold, cobalt and nickel. Red lines separate Volcanogenic Massive Sulphide (VMS), gold (Au) and porphyry occurrences. The central box represents the middle 50% of the data, between Q1 and Q3. The central line represents the median, while the solid black circle represents the mean. The whiskers are 5% and 95% values, and the outliers (top and bottom 5% of data) are represented by open symbols.

volcanic rocks with minor amounts of felsic tuff. Consequently, we would expect Kuroko- and Bathurst-type VMS deposits in the upper TVG that are prospective for Zn-Pb-Cu-(Au-Ag) mineralisation, and Noranda-type (bimodal-mafic) deposits in the Beaghmore Formation that are Zn-Cu-(Au-Ag)-rich (Galley *et al.* 2007; Piercey *et al.* 2011).

The lack of exposure and drilling at Bonnetty Bush means that an evaluation of its potential is highly speculative. However, the Beaghmore Formation includes extensive jasper/ironstone, and quartz-and-chlorite-altered tuffs, which are indicators of VMS

hydrothermal activity (Galley *et al.* 2007; Hollis *et al.* 2015). The base-metal sulphide mineralisation in Bonnetty Bush prospecting samples, with elevated Au grades represents a typical Noranda-type signature (Galley *et al.* 2007). While the presence of pyrrhotite usually indicates the higher temperature Cu-rich parts of VMS systems (Hannington 2014; Piercey *et al.* 2023), galena and Ag commonly occur in the lower temperatures parts of these systems, and Te-Bi could indicate a magmatic volatile contribution (e.g. Sillitoe *et al.* 1996; Moss *et al.* 2001; Mercier-Langevin *et al.* 2011; Martin *et al.* 2019;

Patten *et al.* 2020; Denisová *et al.* 2024). This could be explained by the dynamic nature of these systems, as they may have variable magmatic inputs carrying Ag-Te-Bi to the hydrothermal fluids, and are usually of lower temperatures during their waning stages, favouring Pb-rich mineralisation (e.g. Hackett River deposit, Grant *et al.* 2015; Ming deposit, Brueckner *et al.* 2016; Pilote *et al.* 2020, and the Ice deposit, McDonald *et al.* 2018).

Within the Greencastle and Broughderg formations, the rhyolite and tuff hosted Cashel Bridge, Cashel Burn and Aghascrebagh showings share similar chloritic and sericitic alteration, and quartz-carbonate veins associated with dominantly Zn-Pb-rich (up to 8.8% and 4.0%, respectively) mineralisation and lesser Cu mineralisation (up to 1.05%). This is reflected in Table 1, which shows the much higher base-metal concentrations for these localities when compared to all other studied localities, and in previous exploration reports (Hollis *et al.* 2011; Hollis 2012). These alteration styles and base-metal associations are typical of Bathurst and Kuroko-type VMS systems which can also be Au-rich, such as the Buchans district (16Mt at 14.51% Zn, 7.56% Pb, 1.33% Cu, 1.37ppm Au) and Tulks Hill (0.43Mt at 4% Zn, 1.6% Pb, 0.9% Cu, 1.2ppm Au) deposits in Newfoundland, (e.g. Galley *et al.* 2007; Agnerian 2008; Thurlow 2010; Mercier-Langevin *et al.* 2011; Ross and Mercier-Langevin 2014; Fuchs *et al.* 2019; Piercey 2023). At Cashel Bridge, geochemical data returned the highest geometric average Mn content (1545.6ppm) of the VMS occurrences (Table 1), which is typically associated with lower temperature venting and alteration (Peter and Goodfellow 1996; Peter *et al.* 2003; Franklin *et al.* 2005; Galley *et al.* 2007; Slack 2012). Nevertheless, the presence of bedded sulphides in petrographic and grab samples, as well as the elevated base and precious-metal contents of historic drilling and prospecting samples, suggests this is a potential future target for exploration. Cashel Burn stands out by its high base-metal, As, Te and Au contents (Table 1; Fig. 11B,D). This is partly due to the sampling bias, which only includes sulphide-rich mineralised outcrop and float samples, but is also likely to represent mineralisation at Cashel Burn.

Evidence of late-stage veining, and sulphide recrystallisation and overgrowths, potentially indicate that Au at Cashel Burn, Cashel Bridge and Aghascrebagh could be a later addition associated with late Grampian Au mineralisation (e.g. Rice *et al.* 2016), especially given their proximity to the Omagh thrust. Importantly, across VMS

occurrences of the TIC, a pattern of Bi-Te-Ag-Au association occurs, which is a similar signature to the Curraghinalt Au deposit (e.g. Stratford 2020; Hollis *et al.* this volume). This tentative link between Au-rich VMS-style occurrences of the TIC and the Curraghinalt Au deposit in the Dalradian warrants further investigation.

Although minimal information is available for Mountfield, styles of hydrothermal alteration and veining are similar to other described VMS occurrences. Minor pyrite-chalcopyrite mineralisation in basalts and black shales along with ironstone are indicative of minor VMS hydrothermal activity. Ironstones can form from hydrothermal fluid venting on the seafloor in VMS systems (Galley *et al.* 2007; Hannington *et al.* 2014; Hollis *et al.* 2015; Piercey *et al.* 2023). The very low concentrations of base and precious metals and the pronounced negative Eu anomaly of the ironstone sample collected from the floor of Mountfield Quarry compared to other VMS proximal signatures from ironstones in Tyrone and globally (e.g. Hollis *et al.* 2015) suggests it is distal to any potential site of higher-temperature venting.

Gold targets

In the TIC, the Broughderg, Crosh and Tullybrick Au targets are found in the felsic tuff dominated parts of the Broughderg Formation, which are adjacent to the Omagh thrust (Fig. 2). Given that the Omagh thrust represents the surface expression of a major terrane bounding crustal suture, it is perhaps unsurprising that the world-class Curraghinalt Au deposit (6 Moz), and vein-hosted Au mineralisation in the adjacent TVG, occur near this structure. High Au assays from trenching, shallow drilling and prospecting at these localities could be another expression of the same hydrothermal-magmatic fluids.

Geochemically, this mineralisation style in the TIC has lower base-metal contents, although some higher maximum values occur in isolation (up to 4.24% Pb, 1.25% Zn and 1.35% Cu), and is relatively enriched in Sb, Mn, Te, Hg and W (Table 1). Enrichments in these elements suggest that a magmatic component was involved in the hydrothermal fluids (e.g. Goldfarb *et al.* 2005; Tomkins 2013) or alternatively that the auriferous fluids interacted with black shales in the crust (e.g. Gregory *et al.* 2015). This interpretation correlates with recent work at Curraghinalt, which invokes a strong magmatic input to the mineralising fluids based on He and S isotope signatures (Lyell *et al.* 2025). Curraghinalt also contains significant quantities of

tetrahedrite-tennantite, tellurides (including Ag, Au, Bi and Pb-tellurides) and rare molybdenite (Parnell *et al.* 2000; Rice *et al.* 2016; Hollis *et al.* this volume). Such a correlation is further supported by the few hundred ppm Mo enrichments (and identification of molybdenite) in some samples from Crosh and Broughderg. Relatively Ni-Co rich samples are seen at these localities, with higher concentrations of As observed at Crosh (Table 1; Fig. 11B,E,F). This As enrichment is not seen at the other two localities, although rare arsenopyrite is observed in petrographic samples from Broughderg. Local zones of Co enrichment recorded at Curraghinalt (Hollis *et al.* this volume) are associated with arsenopyrite and arsenian pyrite.

While labelled as Au targets, Tullybrick, Broughderg and Crosh remain prospective for VMS mineralisation (Hollis *et al.* 2014, 2015, 2016), which is reflected by the large quartz-sericite-pyrite alteration halos, and localised zones of base-metal sulphides often associated with intense chlorite alteration. At Broughderg, this is exemplified by Mn assays of up to 3.15%, which is most likely related to the chert-ironstone unit of hydrothermal origin located in the area (Hollis *et al.* 2015, 2016). Whilst the extensive hydrothermal alteration is consistent with VMS mineralisation (Hollis *et al.* 2014), their proximity to the Omagh thrust (Fig. 2) suggests that a later orogenic Au overprint could also be responsible for some of the mineralisation, either during the late Grampian or Scandian orogenic events (Rice *et al.* 2016; Shaw *et al.* 2022). This is supported by the fact that the zones of Au enrichment are associated with quartz veining that crosscuts the regional foliation. Such a relationship between VMS and orogenic and/or magmatic overprints has been suggested for multiple Au-rich VMS systems, where the pre-existing syn-volcanic faults feeding syngenetic deposits act as conduits for orogenic/magmatic fluids during post-VMS orogenesis and pluton emplacement (e.g. Nubian Shield, Northeastern Africa, Johnson *et al.* 2017; Bryah Rift Basin, Australia, Ramos *et al.* 2021; Noranda district, Canada, Jørgensen *et al.* 2022).

Rice *et al.* (2016) described a series of narrow sericite- and molybdenite-bearing microshears that cut the auriferous veins at Curraghinalt. These were dated by $^{40}\text{Ar}/^{39}\text{Ar}$ and Re-Os geochronology of sericite and molybdenite, respectively. Metamorphic muscovite from wall-rock clasts incorporated into the Curraghinalt resource veins was also dated through $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology. A combined age for the molybdenite and sericite was also presented at $455.8 \pm 3.0\text{Ma}$, constraining

the age of the Curraghinalt Au deposit to the late Grampian, following peak metamorphism at $c.475\text{--}465\text{Ma}$. By contrast, structural constraints from the Dalradian-hosted Cavanacaw Au deposit and Sperrin mountains minor occurrences suggest these are Scandian in age ($c.430\text{--}425\text{Ma}$; Shaw *et al.* 2022). Detailed structural analysis and geochronology (Re-Os, $^{40}\text{Ar}/^{39}\text{Ar}$) is needed to constrain the age of the Au occurrences at Broughderg, Tullybrick and Crosh.

Low/intermediate epithermal – Cashel Rock

The Cashel Rock (Fig. 2) quartz-flooded and brecciated rhyolite has the highest maximum Au grades of all of the studied occurrences (up to 114.8ppm; Table 1, Fig. 11B) in the TIC but also has the lowest sulphide abundance by a wide margin, although some Pb-Zn-Cu mineralisation also occurs in an underlying stockwork zone (Hollis 2012). Such a setting for Au is typical of epithermal systems (Hedenquist *et al.* 2000; Sillitoe and Hedenquist 2003; Dilles *et al.* 2010; Wang *et al.* 2019; Dilles and John 2021). Cashel Rock has characteristics of both a base-metal-poor and Au-Ag-rich low sulfidation system, and a more base-metal-rich intermediate sulfidation epithermal system. It therefore could represent a transition between the two types (e.g. La Guitarra deposit, Mexico, Camprubí and Albinson 2007).

Cashel Rock has long been interpreted to be akin to a VMS system, in part due to the base-metal sulphide-rich chloritic stockwork underlying the quartz-flooded zone (Hollis *et al.* 2014). However, these features are also common in epithermal systems (Dilles *et al.* 2010 and references therein). Furthermore, the much lower Co-Ni contents of the mineralisation compared to other VMS occurrences in the area (e.g. Cashel Bridge, Cashel Burn), along with bonanza Au grades and low sulphide abundance suggest a low to intermediate epithermal system is more likely (Fig. 11D–F). The sulphide fracture-fill of pyrite indicates it is the earliest sulphide phase, followed by the base-metal (Pb-Cu-Zn), electrum and telluride assemblage, and potentially later pyrite overgrowths. This is supported by BSE images, where the pyrite shows compositional zoning (Fig. 8).

Porphyry – Formil

Porphyry Cu-Mo mineralisation has been recognised in the TVG associated with 469–464Ma felsic-intermediate and younger intrusive rocks (Leyshon and Cazalet 1976; Hollis *et al.* 2011) (Fig. 2). The Formil area contains multiple quartz porphyry intrusions,

tabular tonalite intrusive bodies, and volcanic units with intense quartz, sericite and argillic alteration (Leyshon and Cazalet 1976; Hollis *et al.* 2012, 2016). These are interpreted to represent multiple, well-established and distinct alteration zones present in porphyry systems (Sillitoe 2010). The superposition of these distinct alteration zones is to be expected as the area is extensively tectonised and locally repeated, due to internal thrusting in the uppermost TVG near the Omagh thrust.

While historic drilling from Formil has returned disappointing values (e.g. 90m at 0.16% Cu, 70m of kaolinite altered quartz porphyry; Riofinex 1974), more recently discovered outcrops of semi-massive pyrite with disseminated magnetite, plus extensive chalcopryrite veining in rhyolite and quartz porphyry, represent encouraging new targets (Hollis *et al.* 2011, 2016).

Samples analysed from Formil contain pyrite, chalcopryrite, molybdenite, magnetite, minor inclusions of Bi-Te phases and quartz-carbonate veining with distinct sericite alteration halos (Fig. 9A–B). This is indicative of higher temperature A and B type veins typically found proximal to the potassic zones of porphyry systems and contemporaneous with the main chalcopryrite stages of mineralisation (Sillitoe 2010). Whole rock geochemical data from Formil yielded the highest geometric average Mo concentrations from the TIC, with elevated Cu (indicators of higher temperature zones), and depleted As and Sb (indicators of lower temperature zones) (Heinrich *et al.* 2005; Sillitoe 2010; Kouzmanov and Pokrovski 2012; Deditus *et al.* 2014; Halley *et al.* 2015) (Table 1; Fig. 11B–C). Coeval Cu-Mo±Au and Bi-Te (although scarce) mineralisation are known to occur in porphyry systems, which could relate to the timing of the different stages of mineralisation (i.e. Mo and Cu ‘stages’, etc.), parameters of the fluid source, overprinting from multiple magmatic pulses (Sillitoe 2010; Seo *et al.* 2012; Cernuschi *et al.* 2023) and/or structural dissection and stacking of the system related to the Grampian orogenic cycle (e.g. Chew *et al.* 2008; Hollis *et al.* 2012; Van Staal and Dewey 2023). At Formil, multiple intrusions are recorded from tonalite to younger units of quartz-porphyrific dacite. High Mo in porphyry deposits is associated with more felsic intrusions, whereas Cu-Au tends to be associated with more intermediate intrusions (Sillitoe 2010; Seo *et al.* 2012; Heinrich 2024).

While promising, future exploration at Formil might be impaired by the effects of the previously discussed multiple orogenic cycles the area has been involved in, resulting in the dissection of the system

and the stacking of alteration zones and probable elongation of ore zones down dip.

Intrusion related vein systems: Corvanaghan, Golden Hollow and Mulnafye

Vein style mineralisation interpreted to be intrusion related occurs in the Dalradian metasedimentary rocks of the TCI at Corvanaghan Quarry, within the Greencastle Formation at Mulnafye, and is a likely explanation for the mineralised boulder discovered at Golden Hollow (Fig. 2). These occur in different host rocks but have somewhat similar metal assemblages. Vein-related mineralisation at Corvanaghan and Golden Hollow is typified by Cu-Bi-Te-Au-Ag±(W-Ni-Co-Pb)-enrichment, whereas samples examined at Mulnafye have Cu-Au±(Bi-Te)-enrichment. Minor barite was also observed at Corvanaghan and Mulnafye associated with veining.

Felsic-intermediate intrusion-related systems are a permissible explanation for Mulnafye and for some of the element suite at Corvanaghan and Golden Hollow, as they can be rich in Cu-Bi-Te-W-Au and sometimes Ag-Pb (e.g. Sillitoe and Thompson 1998; Thompson *et al.* 1999; Lang and Baker 2001; Hart *et al.* 2007). However, the Ni-Co enrichments observed at these localities are not typical of these systems. At Mulnafye, this kind of magmatic-hydrothermal system is expected to be associated with the c.470Ma tonalitic intrusions that are found in the area. The vein hosted Cu-Au mineralisation occurs towards the top of these intrusions into the overlying volcanic rocks. Barite and tourmaline are commonly found within these systems (Sillitoe and Thompson 1998; Hart *et al.* 2007; Qiu *et al.* 2021) and are expected to be part of the mineralised system. Observed Bi-Te and Ag-Cl phases at Mulnafye are thought to be the product of supergene alteration of Bi-Te-bearing chalcopryrite to covellite+malachite and of Cl-bearing phases such as apatite and micas.

In the TCI, the vein-hosted mineralisation found at Corvanaghan could be related to the emplacement of large tonalitic to granitic intrusive rocks between c.470–464Ma. The neighbouring ophiolitic sequence of the TPG is a potential source of Ni-Co that could have been leached by the ascending hydrothermal fluids driven by these intrusions. Alternatively, the mineralisation signature at Corvanaghan could be equivalent to the poorly-understood ‘five-element’ (Ag-Bi-Co-Ni-As)-type veins, which are thought to involve rifting and overpressured metal-rich Na-Ca-Cl basinal brines (e.g. Kissin 1992; Markl *et al.* 2016; Burisch *et al.* 2017; Kreissl *et al.* 2018). Such systems also commonly include barite as an

accessory phase. Corvanaghan shares a striking resemblance to the Ni-Co-bearing Italian Arburese and Usseglio hydrothermal deposits described by Moroni *et al.* (2019), where mineralisation similar to these five-element systems occurs in relation to shallow brittle fault networks during late to post-orogenic stages. These have a variable enrichment in Cu-Ag-Au-Co-Ni-Pb-Te-Se-As-Bi and occur with accessory barite in Paleozoic-Mesozoic basement rocks and ophiolite sequences (Moroni *et al.* 2019 and references therein). In this case, the mineralisation at Corvanaghan could have formed either syn arc-rifting, or perhaps more likely, they are related to the late/post-orogenic phases of the Grampian orogenic event. Additional structural and mineral-chemical research is required to further characterise these vein systems. The presence of scheelite is also particularly interesting, as this is suggestive of reduced S-type intrusions.

Little information is available for the sulphide mineralisation at Golden Hollow. The strongly mineralised boulder discovered in a stream section at the contact between the TCI and TPG is enriched in Cu-Au-Ag and depleted in Zn-Pb. It was previously interpreted to be Cyprus-type VMS mineralisation based on the observed sulphide assemblage (Mawson 2023). Although some of the base and precious-metal signature concords with this type of system (e.g. Galley *et al.* 2007; Mercier-Langevin *et al.* 2011; McDonald *et al.* 2018; Martin *et al.* 2019; Piercey *et al.* 2023), geochemical assays also return wt.-%-level Bi with the same metal signature seen at Corvanaghan (Table 1). This level of Bi is highly anomalous and might point to magmatic of Bi-Te-Au-Ag to hydrothermal fluids (e.g. De Ronde *et al.* 2011; Deady *et al.* 2022), or hybrid/other mineralisation styles such as five-element type veins as described for Corvanaghan. For further study, sulphide trace-element data, S isotope analysis and fluid inclusion studies on Golden Hollow samples would provide critical information on its formation.

Conclusions

This work highlights the potential of the Tyrone Igneous Complex [TIC] of Northern Ireland as a host for local sources of base, precious and critical metals. Although underexplored, the area is shown to contain multiple targets for a wide variety of commodities. Further, the TIC presents added complexity due to its involvement in multiple orogenic cycles,

which potentially resulted in a combination of late-stage overprinting, dissection of the systems and stacking of alteration and ore zones. Targets in the TIC include multiple mineralisation types, including porphyry Cu-Mo, VMS Cu-Pb-Zn, orogenic Au, epithermal Au $\pm$ (Cu-Pb-Zn), intrusion-related Cu-Au and vein-related Cu-Bi-Te-Au-Ag $\pm$ (W-Ni-Co-Pb). While the Tyrone volcanics (TVG) have historically been the main focus of exploration, this work also highlights the shared potential for mineralisation in the metasedimentary (TCI) and ophiolitic sequences (TPG) preserved in the TIC. An in-depth characterisation of these targets using advanced microanalytical techniques, along with future exploration work in the TIC will be critical in further assessing the viability of these targets.

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