First insights into the sediment-hosted copper mineral system of the Birrindudu Basin, NT – facies analysis and basement source rocks

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Introduction

The Birrindudu Basin is located in northwestern Northern Territory and comprises sedimentary successions of Palaeo- to Mesoproterozoic-age (**Figure 1**). The basin overlies the Granites–Tanami Orogen, Pine Creek Orogen, and parts of the Halls Creek Orogen. Multiple rock groups are recognised in the basin: the Birrindudu Group is located in the south of the basin with a maximum depositional age of ca 1837–1812 Ma; and the overlying Limbunya, Wattie and Bullita groups are in the central part of the basin with a maximum depositional age of ca 1653 to ca 1600 Ma (Dunster *et al* 2013). The sedimentary successions are weakly folded and faulted by large-scale basin structures with multiple reactivation phases but do not present signs of metamorphism (Dunster *et al* 2013). In this basin, the depositional age of Limbunya Group is equivalent to the zinc-hosting McArthur Group (Barney Creek Formation) in the McArthur Basin (ca 1640 Ma; Munson *et al* 2020). However, the mineral potential of the Birrindudu Basin is relatively unknown.

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In order to understand base metal mineralisation in sedimentary basins, such as copper and zinc, we use a combined petroleum/mineral exploration mineral systems approach. This abstract presents a summary of findings on depositional environments, facies variations, and copper source rock evaluation. The outputs allow us to identify potential host- and source-rocks, and favourable conditions for mineralising mechanisms (fluid flow, fluid triggers, mineralising processes), ultimately leading to reduce the exploration search space.

Reconstruction of the depositional environment by facies analysis was carried out on several drill cores of the Birrindudu Basin that intersected the Limbunya, Wattie, and Bullita groups. We used an integrated approach, with a combination of facies associations, lithofacies, gamma ray logs, and HyLogger™ mineralogy, to characterise the Palaeoproterozoic stratigraphy of the basin and the neighbouring Beetaloo Sub-basin (**Figure 2**). The petrographic assessment of selected basin and basement rocks helped to determine potential source- and host-rocks for copper mineralisation. Furthermore, we are currently working on establishing a subsidence history of the basin, a sequence stratigraphic framework, and a drill core study to petrographically describe elevated copper sulfides within different stratigraphic units. The overall aim is to establish

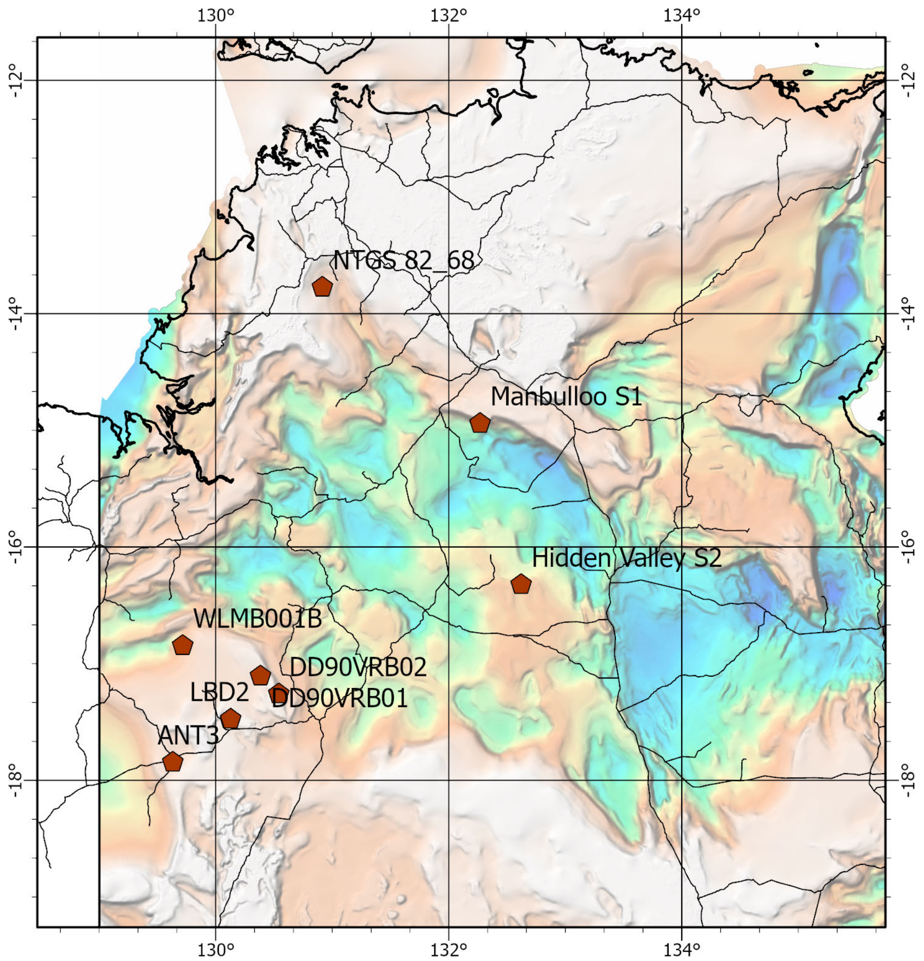

Figure 1. Map showing drillholes studied across the greater McArthur Basin (including the Birrindudu Basin and Beetaloo Sub-basin). Background map – SEEBASE 2020 (NTGS and Geognostics Australia 2021).

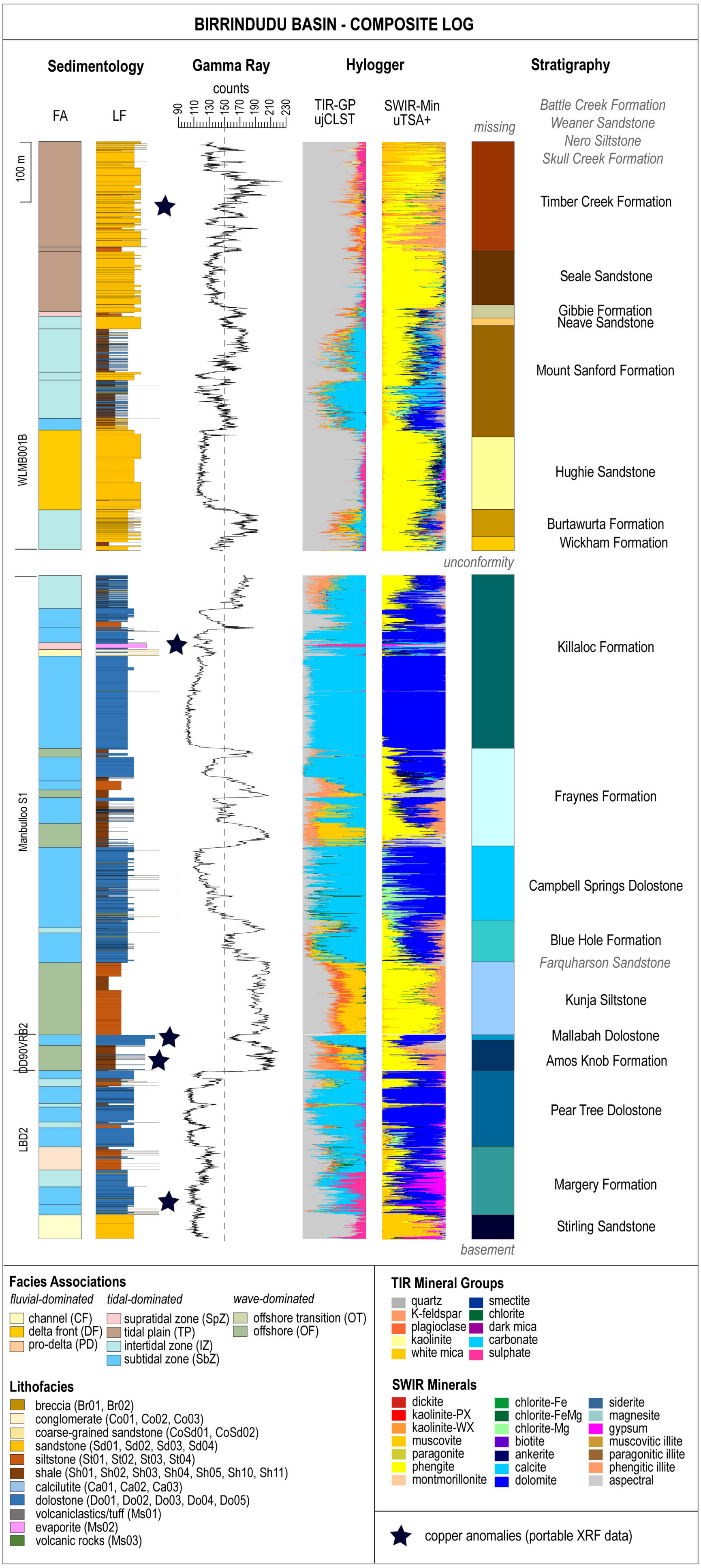

Figure 2. Composite log of stratigraphic intervals represented in studied drill core.

an improved understanding of the sedimentology and to evaluate the basin potential for hosting copper and zinc mineralisation.

Facies analysis and stratigraphy

Facies analysis is the study of lithofacies and their facies associations that are characteristic for depositional environments. It aids in mineral exploration by providing a spatial understanding of distribution of potential host- and source-rocks within the sedimentary basin, as well as fluid flow aquifers. In our study, we identified 32 lithofacies occurring within nine facies associations. The facies associations within the Limbunya Group include offshore, offshore transition, subtidal, intertidal, pro-delta, channel, and supratidal (**Figure 2**). The depositional environment in the Wattie and Bullita groups lacks wave-dominated facies and includes subtidal, intertidal, tidal plain, supratidal, and delta front (**Figure 2**). The overall arid-climate, shallow marine depositional environment is based on diagnostic features such as evaporites (anhydrite, barite) and dominance of shoreface and foreshore facies. A detailed description of the lithofacies and facies associations, and related data packages, can be found in Crombez *et al* (2023). The next step in developing a basin-wide map of facies distribution and basin evolution is the application of sequence stratigraphy, which is currently in progress.

First interpretations on relevant stratigraphic units as part of the sediment-hosted copper mineral system relate to the Limbunya Group (**Figure 2**). The basal channel facies rocks (Stirling Sandstone) were identified as potential fluid pathways for metal-bearing brines. The facies range from pebble conglomerate to coarse-grained sandstones and show intense alteration and leaching of the red-brown, grey sandstones. The Stirling Sandstone lies unconformably over the undifferentiated mafic basement in drillhole LBD2.

Potential host rocks with elevated copper sulfides identified during our study include: 1) subtidal facies - Margery Formation; 2) offshore facies - Amos Knob Formation; 3) intertidal to supratidal facies - Killaloc Formation; and 4) tidal plain/ channel facies - Timber Creek Formation. Ongoing studies focus on the diagenetic relationships of the sulfides and host rocks. Detailed studies on sulfides, as well as diagenetic and detrital mineral abundances, is currently in progress.

Basement source rocks

The investigation of the 'Undifferentiated Basement' beneath the basin successions (Limbunya Group) in the Birrindudu Basin, employing samples from drill core LBD2, has unveiled lithological variations reflecting mafic volcanoclastic rocks variably impacted by metamorphic and hydrothermal alteration. Specifically, examining the basement from ~350 to 500 m depth revealed a transition from 1) dark, distinctly banded, copper-rich strata below ~430 m, to 2) brownish, comparatively copper-poor upper strata with intense Fe-oxide/hydroxide alteration and veining, extending up to the unconformable contact with the overlying basin sediments at ~350 m (**Figure 3**).

Thin section microscopy, as well as Tescan Integrated Mineral Analyzer (TIMA) mineral and XRF elemental distribution mapping, revealed the microcrystalline to granular nature of the basement rocks, showing relict, finely bedded, or weakly to distinctly banded textures. The groundmass of all specimens includes microcrystalline quartz, muscovite, clays, biotite and/or chlorite, pyrite, and Fe-oxide/hydroxides (hematite and goethite; **Figure 3**). The latter is particularly prominent in the Fe-oxide/hydroxide-altered upper basement. The deeper succession displays dark bands dominated by microcrystalline quartz with lesser muscovite, while lighter bands are more granular with higher muscovite proportions. Euhedral to anhedral grains, identified as pseudomorphosed andalusite porphyroblasts, exhibit varying secondary mineralogy, including muscovite and clay (halloysite), and occasionally chlorite/biotite or Fe-oxide/hydroxide (**Figure 3**).

The rocks are enriched with chalcopyrite, consistent with the elevated copper concentrations observed in whole-rock analysis. Chalcopyrite distribution varies, occurring throughout the rock groundmass and within the pseudomorphosed andalusite grains (**Figure 4**). Late-stage hydrothermal activity is evident through Fe-oxide/hydroxide-rich veins (goethite plus hematite), ranging from irregular veinlets within the rocks to denser vein networks in the upper, strongly Fe-oxide/hydroxide-altered succession. Chalcopyrite is only observed alongside pyrite and hematite in the deeper veins (**Figure 4**); the upper basement veins are generally goethite-rich but lack pyrite and chalcopyrite.

Collectively, the data from the 'Undifferentiated Basement' suggest a complex metamorphic and hydrothermal alteration history. This includes: 1) contact metamorphism, promoting the nucleation of andalusite; 2) pervasive phyllic alteration (muscovite plus quartz), possibly occurring ~200–300°C, accounting for copper enrichment; and 3) late-stage hydrothermal activity with oxidised, low-temperature fluids (<100–200°C), accounting for Fe-oxide/hydroxide-rich alteration and veining, as well as copper mobilisation. Notably, the upper, oxidatively-altered basement domain shows marked copper depletion (**Figure 3**), suggesting efficient leaching/removal of previously enriched copper by low-temperature hydrothermal alteration.

The mafic volcaniclastic basement rocks could be considered a potential source for copper. The intense leaching and oxidisation of the succession immediately below the unconformable basement-basin interface and intense alteration of the basal sandstones (Stirling Sandstone) in LBD2 (and LBD1, 3 and 4) could be interpreted as evidence of copper leaching from basement rocks by infiltrating basinal brines. This copper may have been transported in the basin succession along the basal Stirling Sandstone aquifer and potential faults. This interpretation is preliminary, but the abundance of copper in overlying reduced strata, such as the Amos Knob Formation, suggests the possibility of sediment-hosted copper mineralisation. Further studies are needed to identify mineralisation mechanisms and triggers, their spatial distribution, and other factors as part of the mineral system.

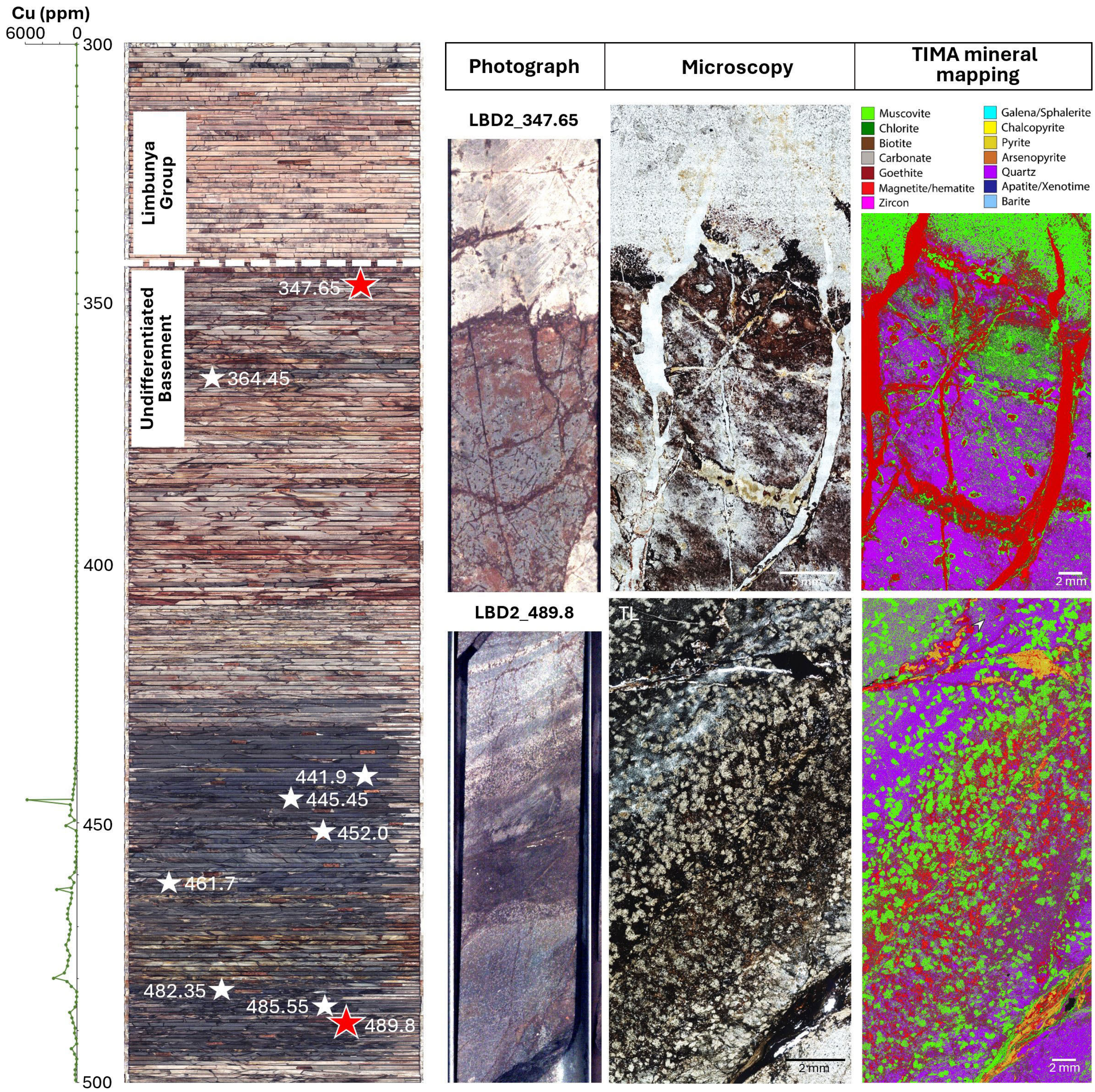

Figure 3. Drill core images and concentrations of copper in drill core LBD2 (between 300 and 500 m), alongside photomicrographs, thin section microscopy results, and TIMA mineral distribution maps of selected samples. White stars pinpoint sampling locations, with large red stars indicating the samples presented in the figure panels on the right.

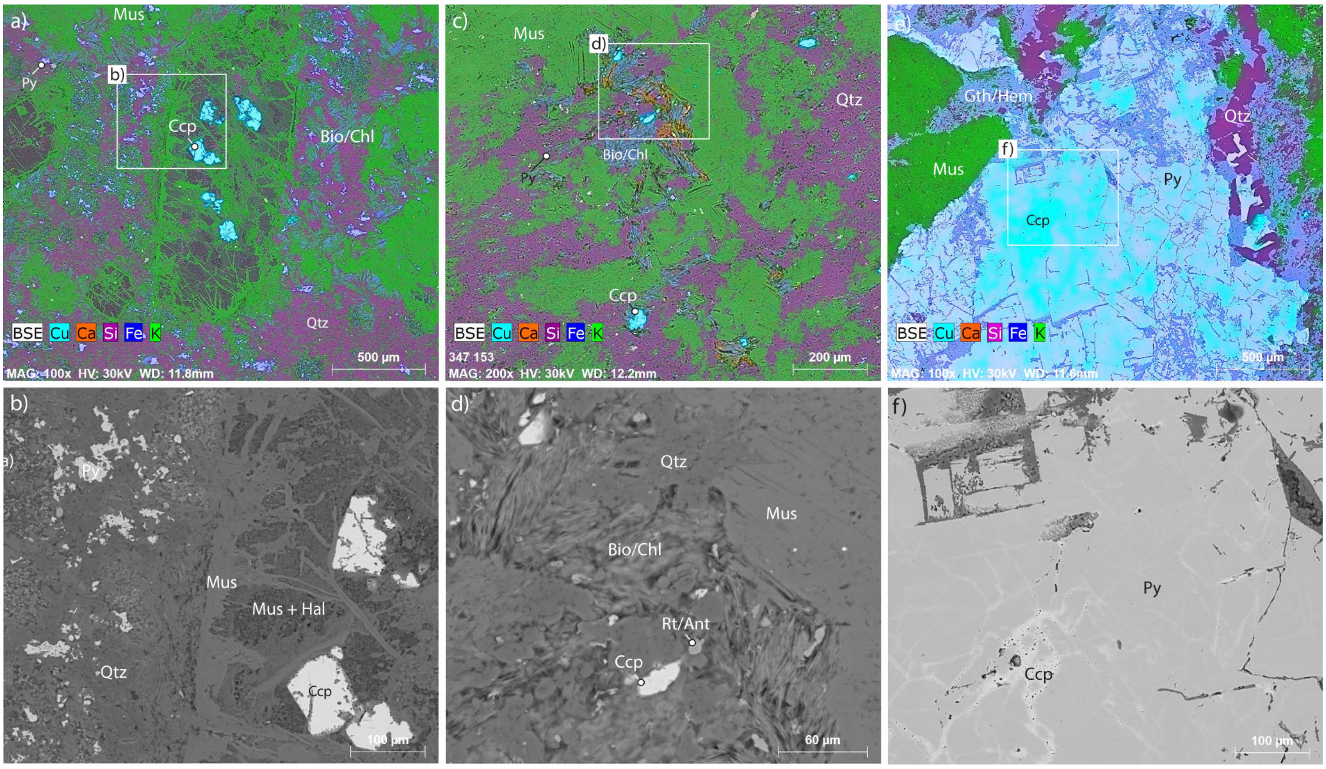

Figure 4. Backscatter electron images and elemental distribution maps (Ca, Si, Fe, K, and Cu) of altered rocks. (**a**, **b**) Chalcopyrite within pseudomorphosed andalusite porphyroblasts. (**c**, **d**) Chalcopyrite within microcrystalline groundmass. (**e**, **f**) Chalcopyrite and chalcopyrite within pyrite- and Fe-oxide/hydroxide-bearing hydrothermal veinlets. Abbreviations: Ant = anatase; Bio = biotite; Ccp = chalcopyrite; Chl = chlorite; Gth = goethite; Hal = halloysite; Hem = hematite; Mus = muscovite; Py = pyrite; Qtz = quartz; Rt = rutile.

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