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ATLAS OF REGOLITH MATERIALS FROM THE WEATHERED ZONE, NEW COBAR DEPOSIT

K.G. McQueen, K.M. Scott, P.G. Ogilvie and B.R. Crowther

CRC LEME OPEN FILE REPORT 240

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(CRC LEME Restricted Report 162R, 2001
2nd Impression 2008)

CRC LEME is an unincorporated joint venture between CSIRO-Exploration & Mining, and Land & Water, The Australian National University, Curtin University of Technology, University of Adelaide, Geoscience Australia, Primary Industries and Resources SA, NSW Department of Primary Industries and Minerals Council of Australia, established and supported under the Australian Government's Cooperative Research Centres Program.

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ABSTRACT

A range of materials from the weathered zone of the New Cobar deposit (145° 51’ 19” E, 31° 31’ 4”S) have been identified and assembled into an atlas to assist recognition and description of these materials during mining of oxide ore. The dominant minerals present are hematite, goethite, quartz (both relict primary and secondary), kaolinite and relict muscovite. Lithiophorite and coronadite are widespread manganese minerals in the oxide zone. Malachite occurs as vein fillings in the oxide zone and chalcanthite has been detected at depth. Other minor oxide zone minerals detected include: anglesite, hinsdalite, hollandite, santaclarite, plumbogummite and pyromorphite. Covellite and native copper are present in the upper part of the supergene zone. A sooty or dusty type of magnetite has been found in partly weathered material and care should be taken not to confuse this with chalcocite. Some sulfides, particularly pyrite, persist up into the oxidised zone in relict unweathered material.

Supergene gold has been isolated from high-grade oxide material 10 m below surface. There are high levels of Pb associated with some oxide material. Lead and Cu are hosted in hematite, goethite, coronadite and lithiophorite. Some coronadite is also associated with high levels of Cu, Co and Ni, these elements possibly occurring in a separate intergrown phase. Concentrations of Ce in small areas of the weathered zone are related to a separate Ce mineral, probably bastnaesite or cerianite. Zinc appears to have been strongly leached from the oxide zone and no secondary Zn minerals have been detected. Similarly As is low and no separate arsenic minerals were identified by this study.

CONTENTS

1. INTRODUCTION

This atlas was prepared at the request of the geological staff of Peak Gold Mines Pty Ltd to assist in identification of materials likely to be encountered in mining oxide ore at the New Cobar deposit (145° 51' 19" E 31° 31' 4" S), 2.5 km southeast of Cobar, NSW. Compilation of the atlas is part of a larger study being conducted by CRC LEME to investigate the mineralogy and geochemistry of the oxidate and supergene zones of the New Cobar gold deposit (Scott and McQueen, 2000; 2001).

The atlas is designed to show general ferruginous textures and then consider examples of white/bluish, brown/black, iridescent and dull black coloured coatings and secondary Cu phases and features to facilitate their correct mineralogical identification. Lists of the minerals observed and the likely hosts for specific elements at New Cobar are also presented (Appendix I).

2. SAMPLING

Most samples (numbers NC-10 to NC-21) described in this atlas were collected from the New Cobar South open pit by Peter Leah (Peak Gold Mines Pty Ltd) to exemplify the range of distinctive materials encountered in the pit during the initial phase of mining to depths of about 30 m during 1999. A small number of samples were taken from diamond drill holes DD97NC0059, DD97NC0060 (see Figure 1 for location). The sampling was not designed to be comprehensive.

3. MINERAL IDENTIFICATION

Minerals in the regolith materials were identified by a combination of optical microscopy, X-ray diffraction analysis (Appendix II), scanning electron microscopy (Appendix III), qualitative energy dispersive analysis and quantitative electron microprobe analysis. For several samples, these techniques were complemented with major and trace element analyses of bulk material by instrumental neutron activation analysis (NAA) and inductively coupled plasma emission mass spectrometry (ICP-MS) after an acid dissolution (see Scott and McQueen, 2000).

4. GENERAL COMMENTS

Weathering effects at New Cobar extend to about 130 m below the surface (10155 m RL: Figure 2). There is a zone of strong oxidation to a depth of about 73 m (10217 m RL) and then a zone of moderate to weak oxidation extending to between 85 and 107 m (10200-10181 m RL). Secondary alteration effects, including malachite veining and underlying development of supergene chalcocite, native copper and trace covellite, extend from a depth of 76 m to 108 m (10213 –10172 m RL). Some sulfides, particularly pyrite, persist up into the oxidised zone where they are encased in quartz vein material or in chemically impermeable lithorelicts. Depth to the water table at the time of early mining has been reported to be 99-100.5 m (ca. 10186 m RL: Mulholland, 1940; Rayner, 1969).

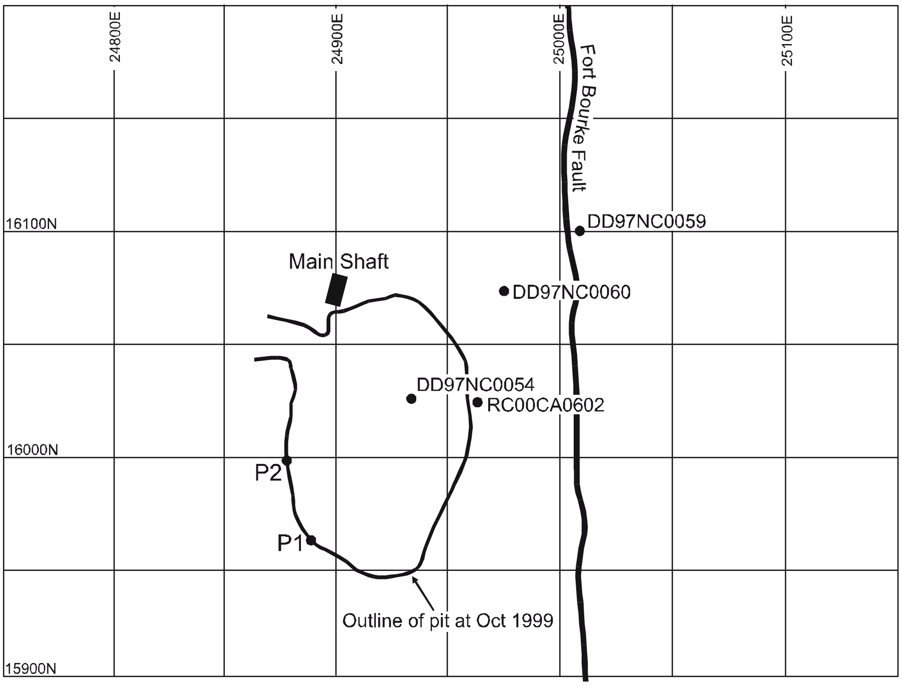

Figure 1. Location of drill holes and profiles at New Cobar South open pit

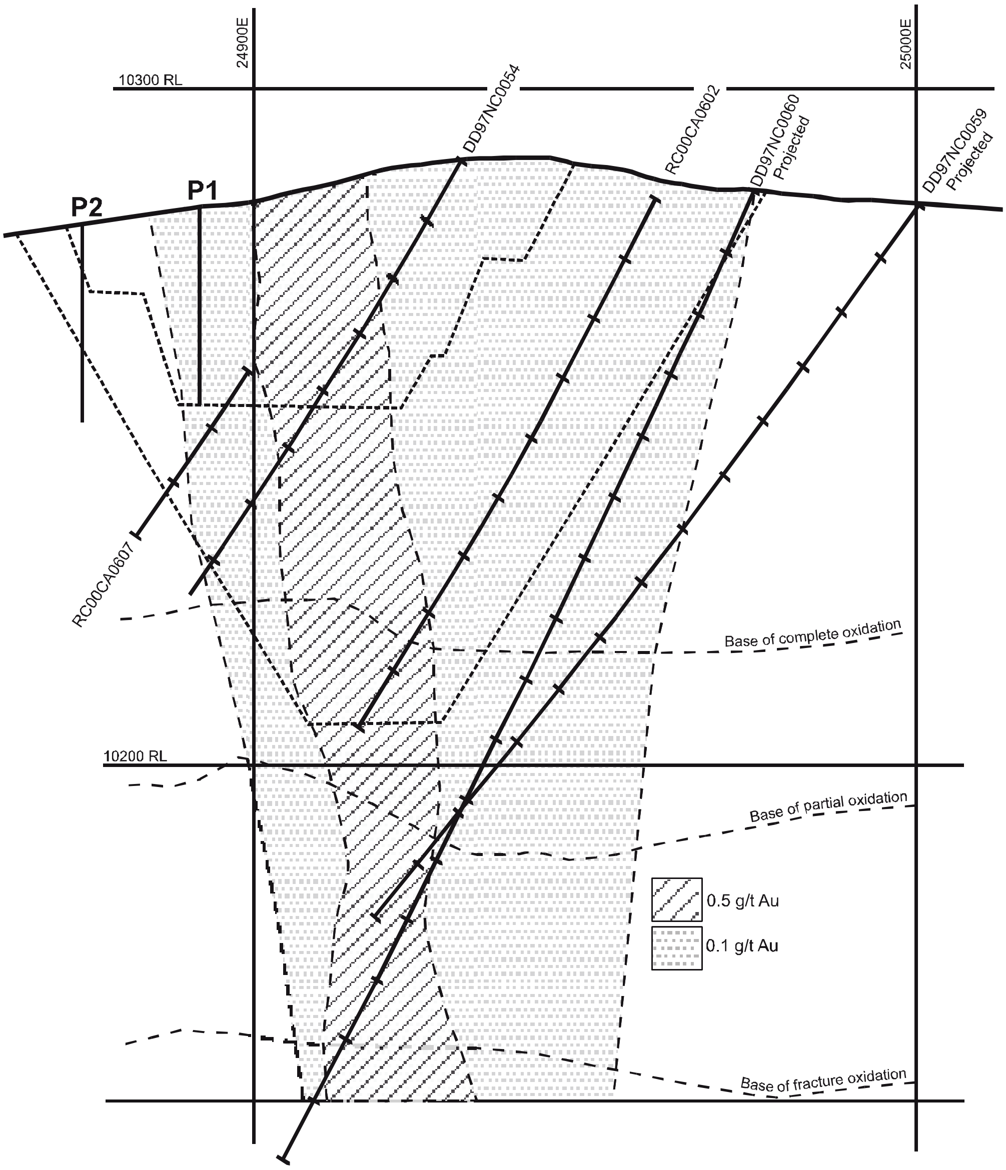

Figure 2. Section at 16025N, New Cobar South open pit. (after Peak Gold Mines Pty Ltd)

The dominant regolith minerals are hematite, goethite, quartz (mostly relict primary, but also some secondary), kaolinite and relict muscovite.

In the oxidate zone the only Cu mineral observed in this study was malachite. Malachite occurs as vein infillings (typically of acicular crystals up to several mm long) and appears to have formed from Cu mobilised in solution, rather than by direct replacement of other primary or secondary Cu minerals.

There are high levels of Pb associated with the oxidised zone materials. A significant proportion of this Pb appears to be fixed in chemically stable or surface-inert phases such as coronadite. Significant Pb is also hosted in hematite and goethite (Scott and McQueen, 2000). Other Pb host minerals detected include anglesite and hinsdalite/plumbogummite (alunite-jarosite group minerals).

No secondary Zn minerals were detected, indeed geochemical data indicate that Zn is generally strongly leached from the oxidised zone (Scott and McQueen, 2000). Most Zn present is probably accommodated in goethite, hematite and Mn oxide minerals.

Arsenic contents of the weathering profile are generally low, up to 700 ppm in some mineralised zones but generally less than 100 ppm (Scott and McQueen, 2000). No As minerals have been detected and As is probably hosted in the Fe oxides/oxyhydroxides.

Lithiophorite and coronadite are widespread manganese minerals in the oxide zone. These minerals may also host Cu and Pb. The development of lithiophorite may be related to conditions of high activity of Al^{3+} from destruction of abundant Al silicates (particularly chlorite and kaolinite) under acid conditions close to the oxidising sulfide lodes. The presence of secondary kaolinite as coatings and in fractures suggests mobility of Al^{3+} during weathering. Lithiophorite is commonly associated with coatings of secondary kaolinite.

Distinctive coatings of white and bluish white material have been noted in the open pit exposures. This material proved to be kaolinite and secondary opaline silica admixed with kaolinite.

NB. Reference is made in profile descriptions to the “stratigraphic footwall” and “stratigraphic hangingwall”. As the lode zone dips steeply east (see Fig. 1) these correspond to the structural hangingwall (or east wall of the pit) and structural footwall (west side of the pit) respectively.

5. ACKNOWLEDGMENTS

Peak Gold Mines geologists (especially Peter Leah) are thanked for collecting many of the samples from the New Cobar open pit and providing information to allow sampling of deeper material from drill core. Roger Heady, Research School of Biological Sciences, ANU, is thanked for providing assistance with scanning electron microscopy for selected samples from the deposit. Kamal Khider assisted with some of the sample preparation. Angelo Vartesi and the Visual Resources Unit at CRC LEME, Floreat Park, are thanked for formatting and producing this report.

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Scott, K.M. and McQueen, K.G., 2001. The mineralogy and geochemistry of the New Cobar Au-Cu mineralisation in the oxidate and supergene zones, Cobar district, Western NSW. CRC LEME Report /E&M Report (in prep).

7. DESCRIPTIONS

PLATE 1: GENERAL FEATURES OF THE PROFILE (PIT EXPOSURES)

A. View of Fort Bourke Hill from the west, showing the upper part of the weathering profile exposed in the east wall of the New Cobar South open pit (December 1998). The siltstone-sandstone sequence in this wall shows considerable hematite-goethite veining and general ferruginous staining, reflecting the more brittle (hence jointing) and porous (hence pervasive staining) nature of these rocks.

B. North wall of the New Cobar South open pit, showing the weathered zone profile to a depth of about 30 m (June 1999). Note areas of darker (more hematite-rich) oxidation after sulfide-rich lode material, particularly in the upper section, and lighter brown (more goethite-rich) staining surrounding the lode material, particularly in the lower part of the profile. The white zone is kaolinite-rich (possibly originally chlorite-rich alteration) material. Also evident are late, low-angle fractures containing goethite-hematite.

C. South wall of the New Cobar South open pit (March 2000), showing oxidised lode, weathered siltstones/sandstones (saprolite) of the stratigraphic footwall (left) and weathered shale/siltstone sequence of the stratigraphic hangingwall (right). Note strong ferruginisation and veining in the footwall sequence. The lode zone shown here is the mineralised profile (P1) described in Scott and McQueen (2000).

D. Low angle ferruginous veining extending laterally from the main lode zone into the stratigraphic footwall in the south wall of the New Cobar South open pit. These veins transect bedding and cleavage.

E. North wall of New Cobar South open pit, showing upper section of the profile (December 1998). The main lode (dark brown zone at left) extends to surface and there is a “blind” lode (at right) developed along a splay structure.

F. Near surface (10 m) expression of the main lode in the north face of the New Cobar South open pit (December 1998). The oxidised lode material here consists mainly of hematite and quartz with lesser goethite and minor kaolinite and muscovite. Samples collected from this material contain up to 68 g/t Au. Much of this gold is of supergene origin (see Plate 10).

PLATE 1:

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PLATE 2: GENERAL FEATURES OF THE PROFILE (DRILL CORE)

A. Drill core from upper zone of strong oxidation (ca. 36 m below surface), showing intense and pervasive iron oxide/oxyhydroxide development in siltstone/sandstone. There are some pseudomorphs and casts after disseminated pyrite and minor black "Mn oxide" diffusions. Note also significant barren quartz veining. DD97NC0060 41-45 m.

B. Drill core from upper zone of strong oxidation (ca. 21 m below surface), showing intense and pervasive Fe oxide/oxyhydroxide development in siltstone. Note irregular quartz veins/veinlets and coatings of black "Mn oxide". DD97NC0059 26 m.

C. Drill core from zone of moderate to weak oxidation in siltstone/sandstone (ca. 76 m below surface), with general pale pinkish Fe oxide/oxyhydroxide colouration and narrow zones of stronger ferruginisation about veins. This material carries disseminated pyrite and up to 3.5% Fe, 1.85% S, 0.26% Cu and 15 ppb Au. DD97NC0060 85-89 m.

D. Drill core from zone of moderate to weak oxidation (ca. 80 m below surface), with Fe oxide/oxyhydroxide development generally restricted to mottles and cleavage-parallel zones including about abundant barren quartz veins. Surrounding rock is greyish with some areas of pinkish colouration. This zone contains 9.6% Fe, 480 ppm S, 0.12% Cu and 60 ppb Au. Sample 138760. DD97NC0059 105 m.

E. Drill core from zone of weak oxidation (ca. 106 m below surface), with partly altered primary sulfides in silicified siltstone. Note generally greenish-grey colouration and minor red-brown Fe oxide/oxyhydroxide zones in upper part (left). Material in this zone (DD97NC0060 117-124 m) generally contains up to 12.5% Fe, 5% S, 0.29% Cu and 2.1 g/t Au. Sample 138721, from 123 m, contains 75 g/t Au, 1.28% Cu and 760 ppm Bi.

F. Drill core of fractured and heavily quartz-veined zone with secondary Cu mineralisation including crystalline malachite infillings along fracture (ca. 96 m below surface). Note also zoned goethite and hematite mottles about some fractures. This material contains 10.4% Fe, 0,08% S, 0.19% Cu and 1.4 g/t Au. Sample 138764. DD97NC0059 113 m.

PLATE 2:

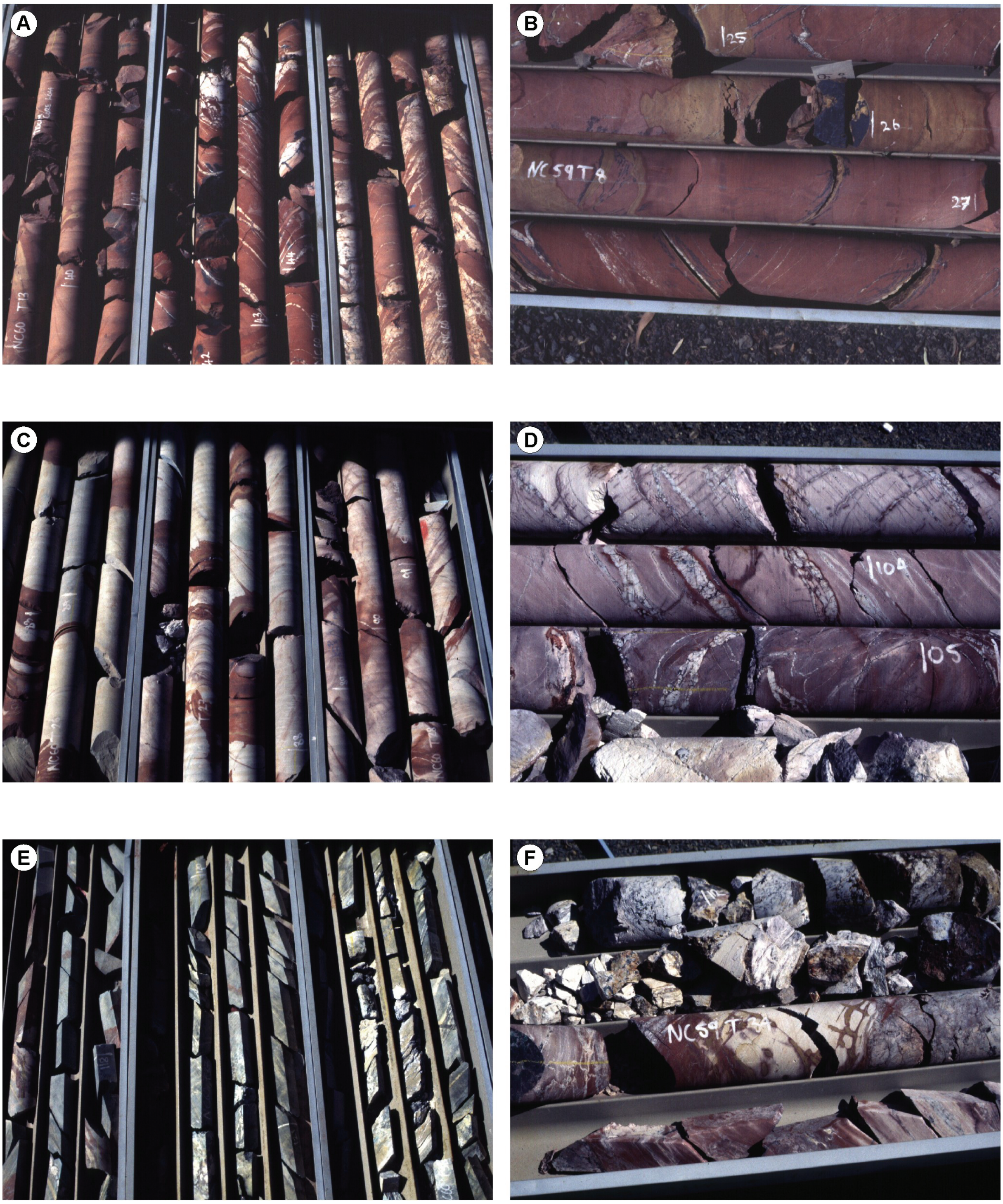

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PLATE 3: FERRUGINOUS MOTTLED AND PSEUDOMORPHED MATERIALS

Redistribution of Fe in solution, followed by re-deposition during oxidation, has resulted in extensive ferruginous veining, mottling and staining of saprock and saprolite surrounding original sulfide-magnetite mineralisation at New Cobar. Pervasive development of Fe oxides/oxyhydroxides has indurated the surrounding weathering zone (particularly in the stratigraphic footwall) and this, together with abundant quartz veining and silicification, has rendered the mineralised zone more resistant to further chemical weathering and erosion so that it is now forms a hill.

A. Ferruginous mottle in siltstone showing zonal development of secondary Fe oxides/oxyhydroxides about a thin, veined fracture. Light-brown zone contains goethite and the darker reddish-brown zone contains hematite. Flame-like protrusions of hematite-rich material are along the cleavage direction (also marked by reglued break along the cleavage). The zonation possibly reflects dehydration or less hydrous conditions favouring hematite stability further from the fracture. Sample 138704. DD97NC0060 84 m.

B. Close up of zoned goethite-hematite mottling.

C. Kaolinite-rich saprolite after strongly weathered shale with hematite/goethite pseudomorphs after disseminated pyrite. Other material from this sample contains 460ppm Cu, 0.47%Pb and 130ppb Au. Sample 138524. Western (stratigraphic hangingwall) of the New Cobar South open pit, barren profile (P2), 8.5 m below the surface.

D. Detailed view of pseudomorphs after disseminated pyrite and hematitic staining in strongly weathered shale.

PLATE 3:

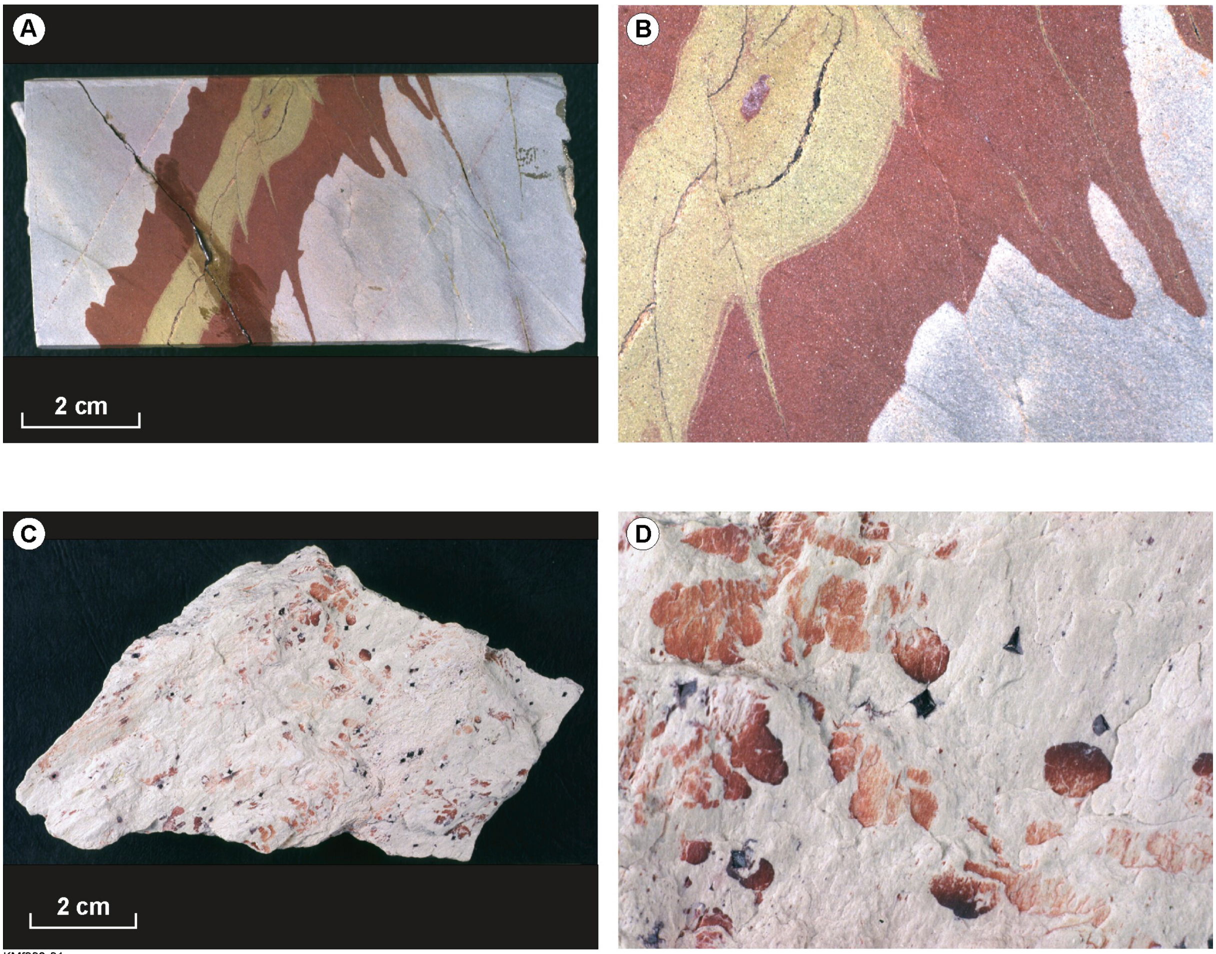

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PLATE 4: WHITE AND BLUISH COATINGS

White and bluish coatings have been observed on weathered surfaces in the open pit. These are largely white deposits of secondary kaolinite and bluish mixtures of secondary and opaline quartz with some intermixed kaolinite.

A. Kaolinite with minor secondary silica coating goethite on a fracture surface. Sample NC-12, New Cobar South open pit.

B. Enlarged view of part of A.

C. Kaolinite with admixed goethite and secondary silica, coating goethite. Sample NC-21. New Cobar South open pit.

D. Enlarged view of part of C.

E. Thin coating of intermixed kaolinite and microcrystalline, partly opaline, quartz. Brown areas are composed predominantly of goethite filling a fracture in siltstone containing quartz and muscovite. Sample NC-15. New Cobar South open pit.

F. Enlarged view of part of E.

PLATE 4:

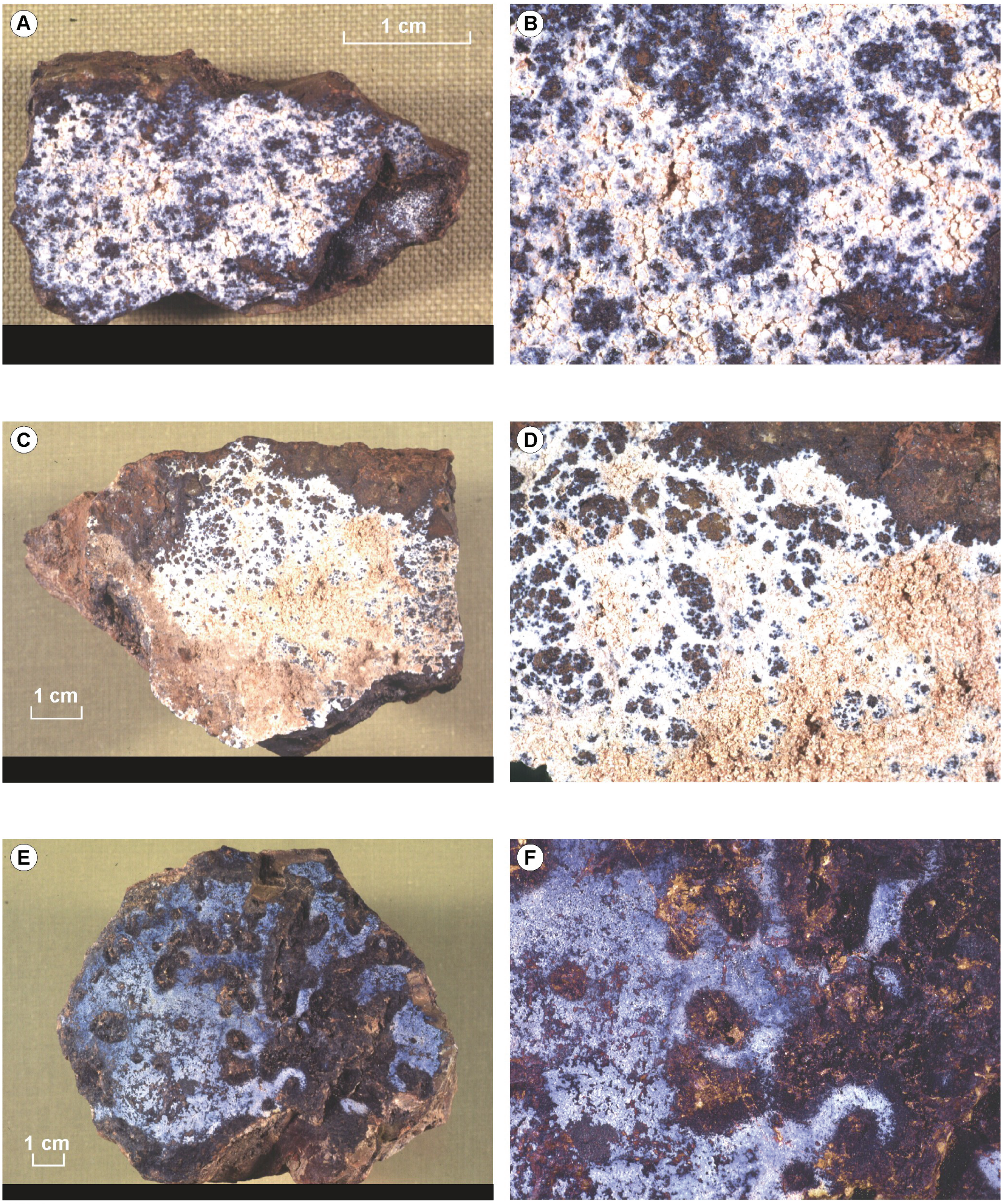

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PLATE 5: BROWN AND BLACK HEMATITE-GOETHITE MIXTURES

Secondary hematite and goethite are abundant in the weathered and oxidised zone of the New Cobar deposit, above the water table. They occur as: *in situ* residual products of oxidised and leached sulfide-rich lode material (gossanous zones); as introduced fillings in fractures and joints in and about the lodes; and as mottles and stainings in porous host rocks. These minerals show a range of forms and colours. Goethite is typically lighter coloured (yellowish brown) and less reddish than hematite, although it can be brownish black or iridescent in some forms (see Plate 6). Black goethite tends to be brighter than Mn oxides and has a brown streak rather than the black streak of Mn oxides.

A. Oxidised lode material composed largely of hematite and quartz with lesser amounts of goethite and minor kaolinite and muscovite. The hematite (grey) has a lustrous, slightly specular appearance. This material also contains small aggregates of crystalline supergene gold, detected after selective dissolution of oxides and silicates (see Plate 10). Geochemical analysis of bulk material indicated 68g/t Au, 0.18% Cu. Sample 138416. North end of New Cobar South open pit, 10 m from surface.

B. Enlarged view of part of A.

C. Goethite with minor hematite and coronadite. This sample shows the small-scale botryoidal form typical of Fe oxides/oxyhydroxides deposited from solution during weathering of the lode zone. This sample also contains quartz and minor amounts of kaolinite, Mn oxides and alunite-jarosite group minerals. Sample NC-13. New Cobar South open pit.

D. Enlarged view of part of C.

E. Thin coating of fine-grained botryoidal hematite and goethite. Sample NC-11. New Cobar South open pit.

F. Enlarged view of E.

PLATE 5:

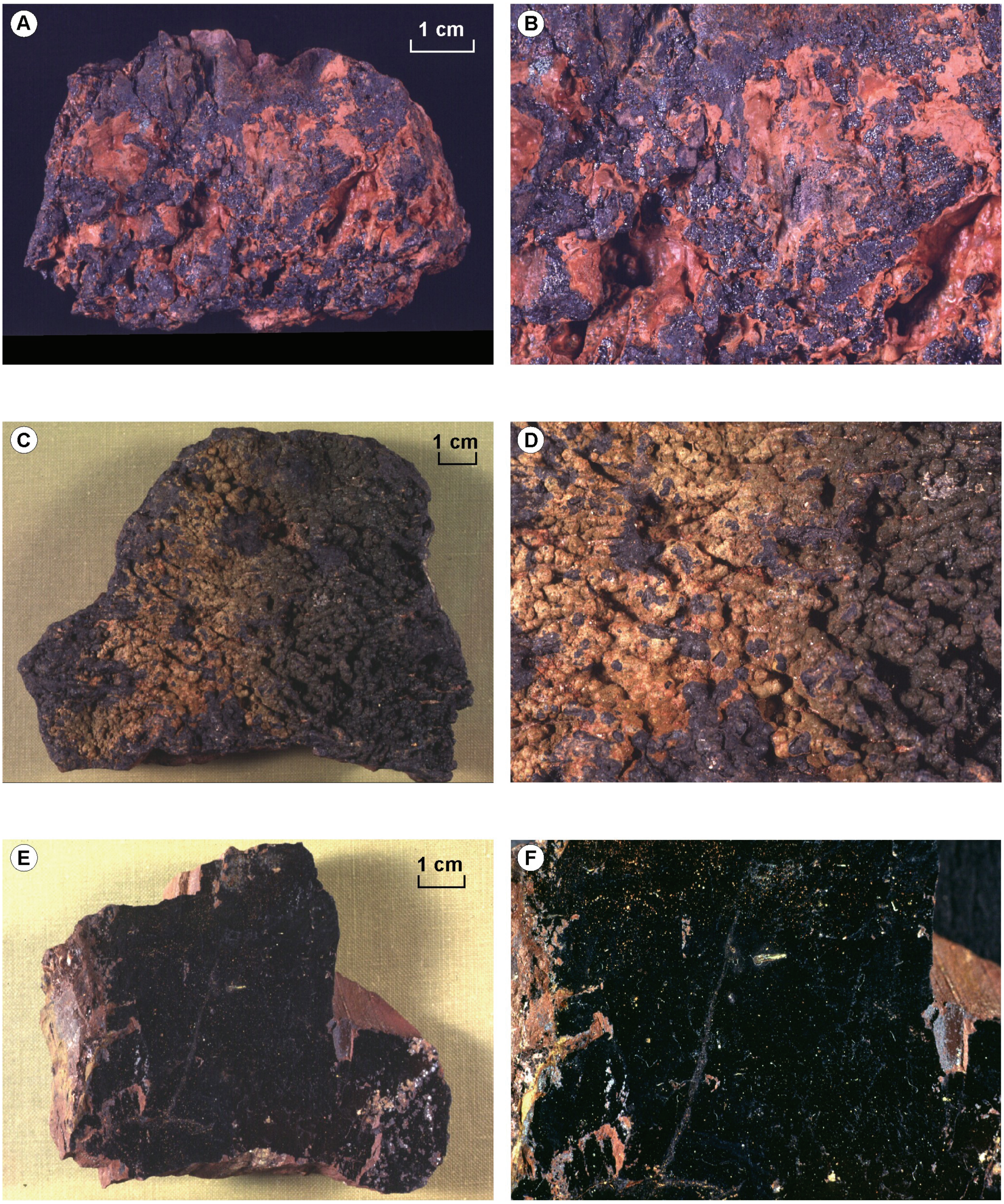

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PLATE 6: IRIDESCENT AND VARIABLY COLOURED OXIDE MINERALS

Bright iridescent coatings observed on exposed surfaces are mainly developed on goethite.

A. The multi-coloured coating in this sample is developed on goethite. The white coating on the left is kaolinite. This sample also contains quartz and trace amounts of hematite, maghemite and possibly a Mn oxide. Sample NC-10. New Cobar South open pit.

B. Enlarged view of part of A.

C. This bluish iridescent coating is developed on goethite showing a well-developed, small-scale botryoidal form. This sample also contains minor hematite and opaline silica. Sample NC-17. New Cobar South open pit.

D. Enlarged view of part of C.

E. The slightly iridescent greenish-grey mineral in this specimen is lithiophorite with a high copper content. The white encrusting material is kaolinite. This sample also contains quartz and minor hematite and goethite. Geochemical analysis of surrounding material indicates 7.6 g/t Au, 0.82% Cu, 230ppm W, 110 ppm Zn and 84 ppm Bi. Sample 138769. DD97NC0059 134 m.

F. Enlarged view of part of E. Note small primary quartz crystals.

PLATE 6:

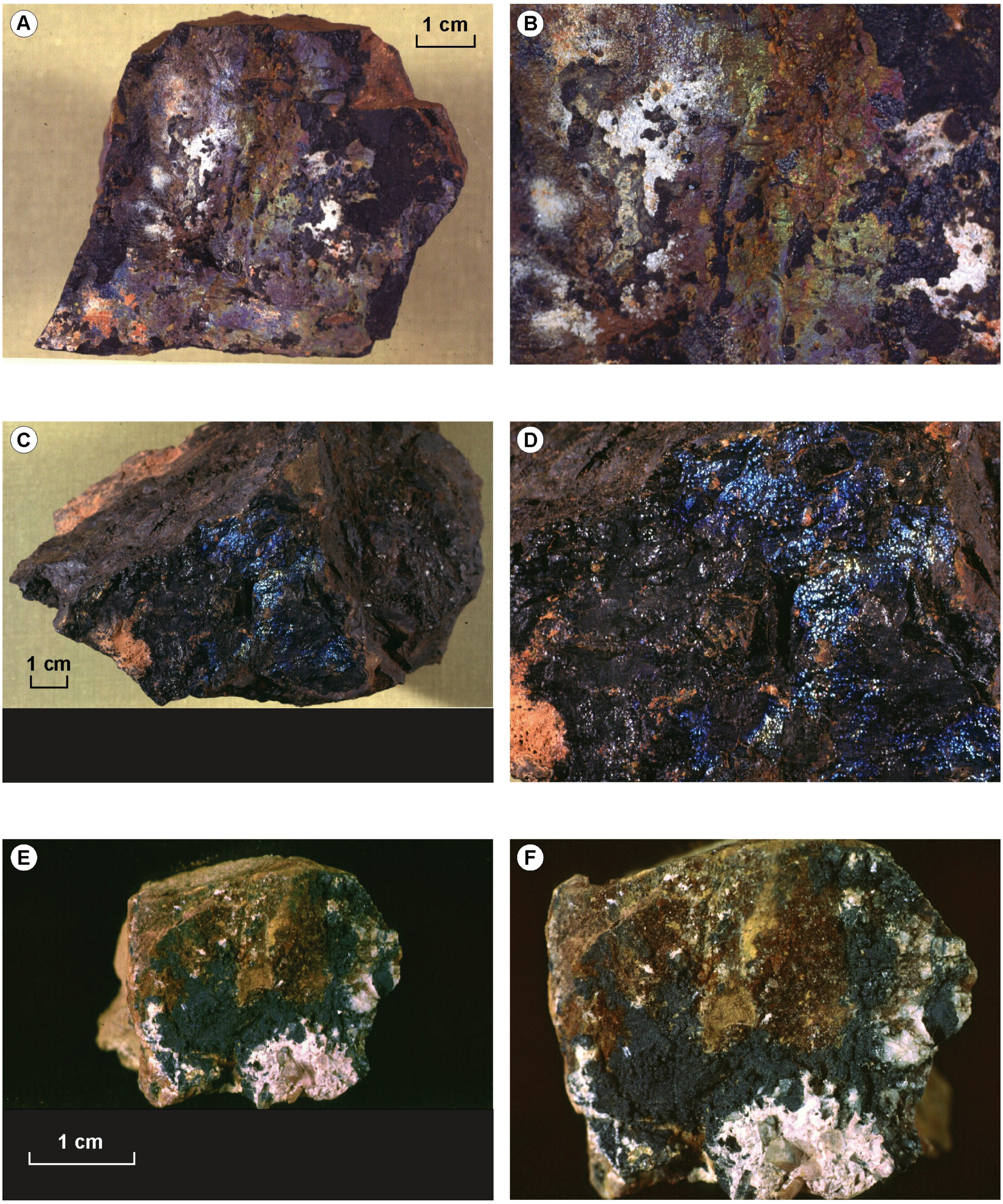

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PLATE 7: BLACK "MANGANESE OXIDE" MINERALS

Coatings of black materials in the open pit have generally been referred to as "Mn oxides". A number of these black coatings were analysed. Some are black goethite, but most consist predominantly of lithiophorite (ideally $(Al, Li)Mn^{4+}O_2(OH)_2$), which appears to be a common secondary manganese mineral in the oxidised zone at New Cobar. The Mn oxides tend to be dull and have a black streak whereas goethite is generally brighter and has a brown streak. The lithiophorite at New Cobar hosts significant but variable amounts of Cu. Lithiophorite has also been detected at the Wood Duck and Peak South (Perseverance) prospects to the south of New Cobar, where it hosts Cu, Zn and some Pb (Cairns et al., 2000).

A. Black lithiophorite impregnating siltstone around a cleavage-parallel quartz vein. The siltstone also shows goethitic staining and contains quartz, muscovite, minor chlorite, kaolinite, and feldspar. Sample 138697. DD97NC0060 42.4 m.

B. Enlarged view of part of A. Note lithiophorite infilling cracks and fractures in the quartz vein and goethite after pyrite in small cleavage-parallel veinlets.

C. Lithiophorite (black) associated with coatings of secondary kaolinite. Minor goethite and hematite are present in the substrate. Sample 138747. DD97NC0059 49 m.

D. Enlarged view of part of C.

E. Greyish-black lithiophorite coating a fracture surface. Material from the zone about this sample contains 1.25% Mn, 0.12% Ba, 0.17% Cu, 120 ppm Zn, <20 ppm Pb and 140 ppm Ce. X-ray diffraction suggests hollandite (ideally $Ba(Mn^{4+},Mn^{2+})_8O_{16}$ and isostructural with coronadite: see Appendix I) may also be present. Sample 138749. DD97NC0059 56 m.

F. Enlarged view of E. Note small-scale botryoidal form of lithiophorite coating.

PLATE 7:

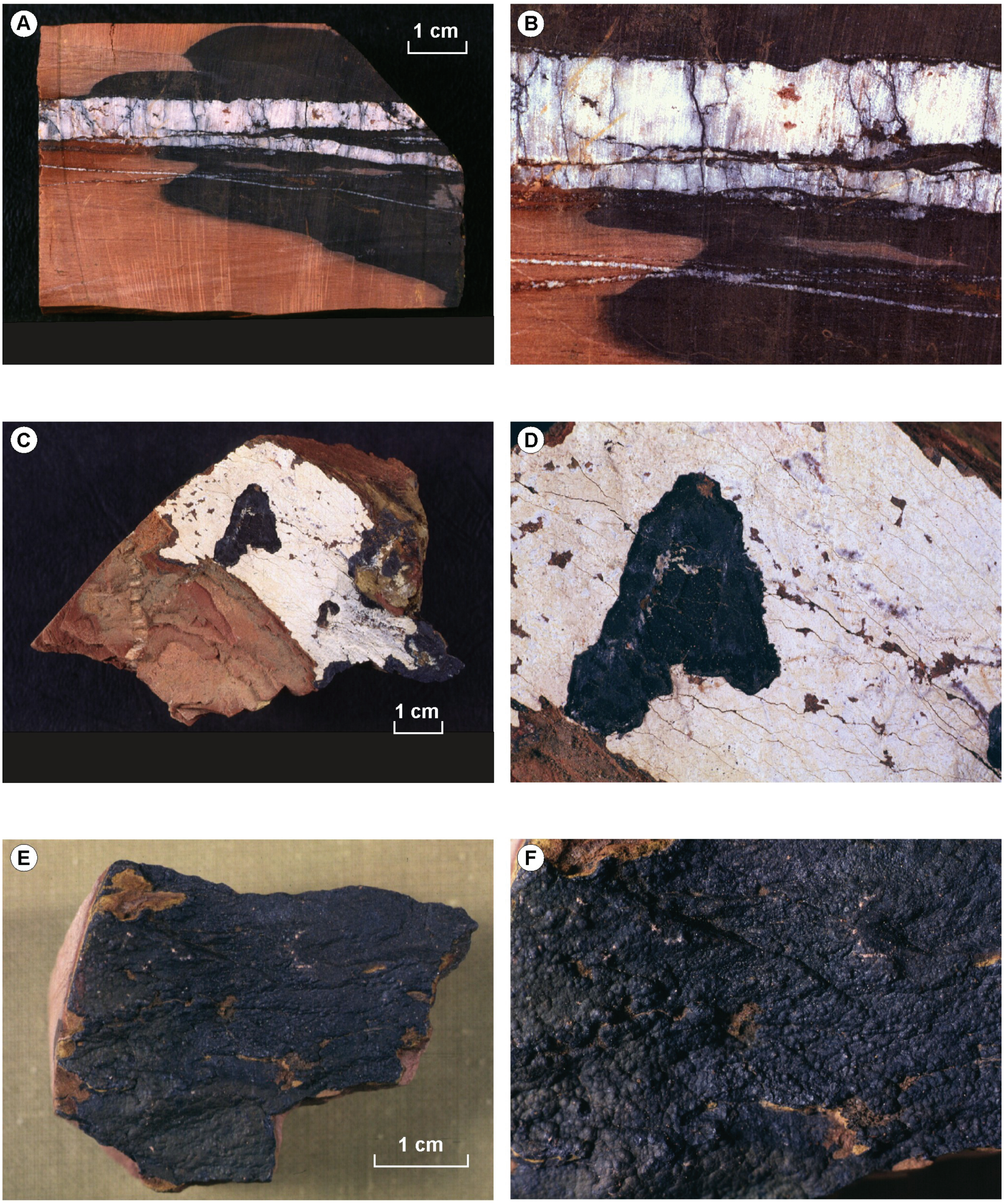

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PLATE 8: CORONADITE

Coronadite (ideally $Pb(Mn^{4+},Mn^{2+})_8O_{16}$) appears to be a widespread Pb-bearing secondary Mn mineral in the oxidised zone of the New Cobar deposit. It is a significant host for the anomalous concentrations of Pb detected in the geochemical profiles investigated. In hand specimen, coronadite at New Cobar is characterised by a steely-grey colour as distinct from the black colours of other Mn oxides/oxyhydroxides.

A. Massive coronadite from a Pb-rich low-angle vein in the oxidised zone. This sample also contains pyromorphite, ($Pb_5(PO_4)_3Cl$), goethite and some maghemite (possibly after magnetite) as well as an alunite-jarosite group mineral (probably plumbogummite or hinsdalite) and trace amounts of hematite. It contains 20.8% Pb, 1.99% Mn and 1.2g/t Au. Sample 138521. New Cobar South open pit, barren profile (P2), 4.9 m from surface.

B. Enlarged view of A. Note steely-grey colour and colloform structure in coronadite.

C. Thin concentric and colloform coatings of coronadite (steely grey) on goethite. Small white patch at right is opaline silica. Sample NC-16. New Cobar South open pit.

D. Enlarged view of C.

E. Coronadite (metallic grey-brown) associated with reddish brown santaclaraite-type mineral (see Appendix I and Plate 11). Other minerals present are goethite, primary and secondary quartz. Sample NC-14. New Cobar South open pit.

F. Enlarged view of part of E.

PLATE 8:

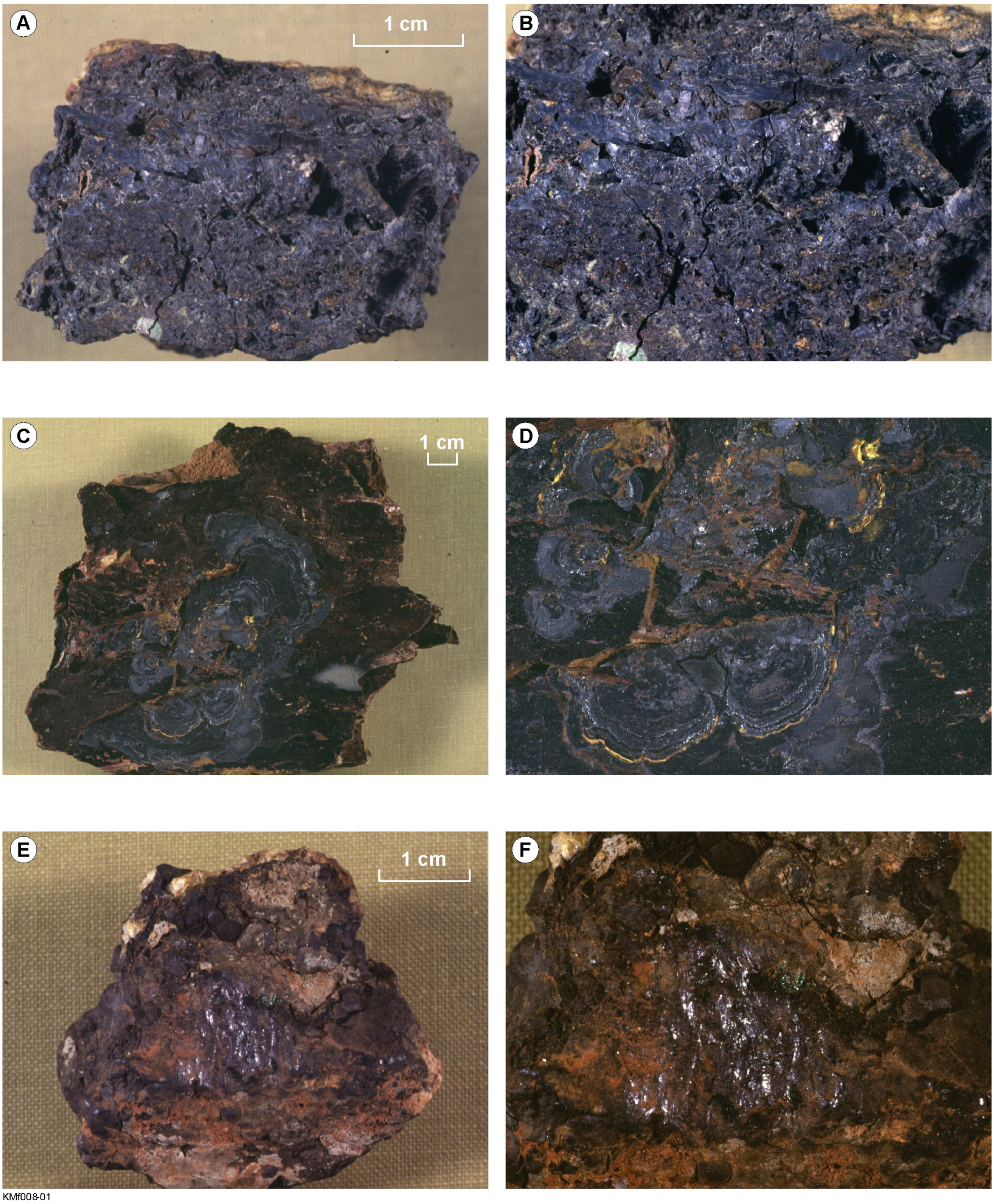


PLATE 9: SECONDARY COPPER MINERALS

The oxidised parts of the profile at New Cobar contain malachite. Significant copper is also hosted by phases such as goethite, hematite and lithiophorite. Secondary minerals lower in the profile include, chalcanthite, chalcocite and native copper. Chalcocite and minor covellite occur as replacements of primary chalcopyrite near the base of the partial oxidation zone.

A. Green chalcanthite ($Cu^{2+}SO_4 \bullet 5H_2O$) associated with powdery magnetite (black). This sample also contains pyrite, quartz, minor chlorite, hematite, goethite, kaolinite and possibly ramsbeckite (ideally $(Cu^{2+},Zn)_{15}(SO_4)_4(OH)_{22} \bullet 6H_2O$). It occurs only 40 m below the surface and was initially thought that the black powdery material in this sample was "sooty chalcocite" but its magnetic properties and subsequent XRD analysis indicated magnetite. This powdery form of magnetite may represent the first stage of weathering of magnetite associated with the lodes. Sample 138833. DD97NC0059 48.5 m.

B. Enlarged view of A.

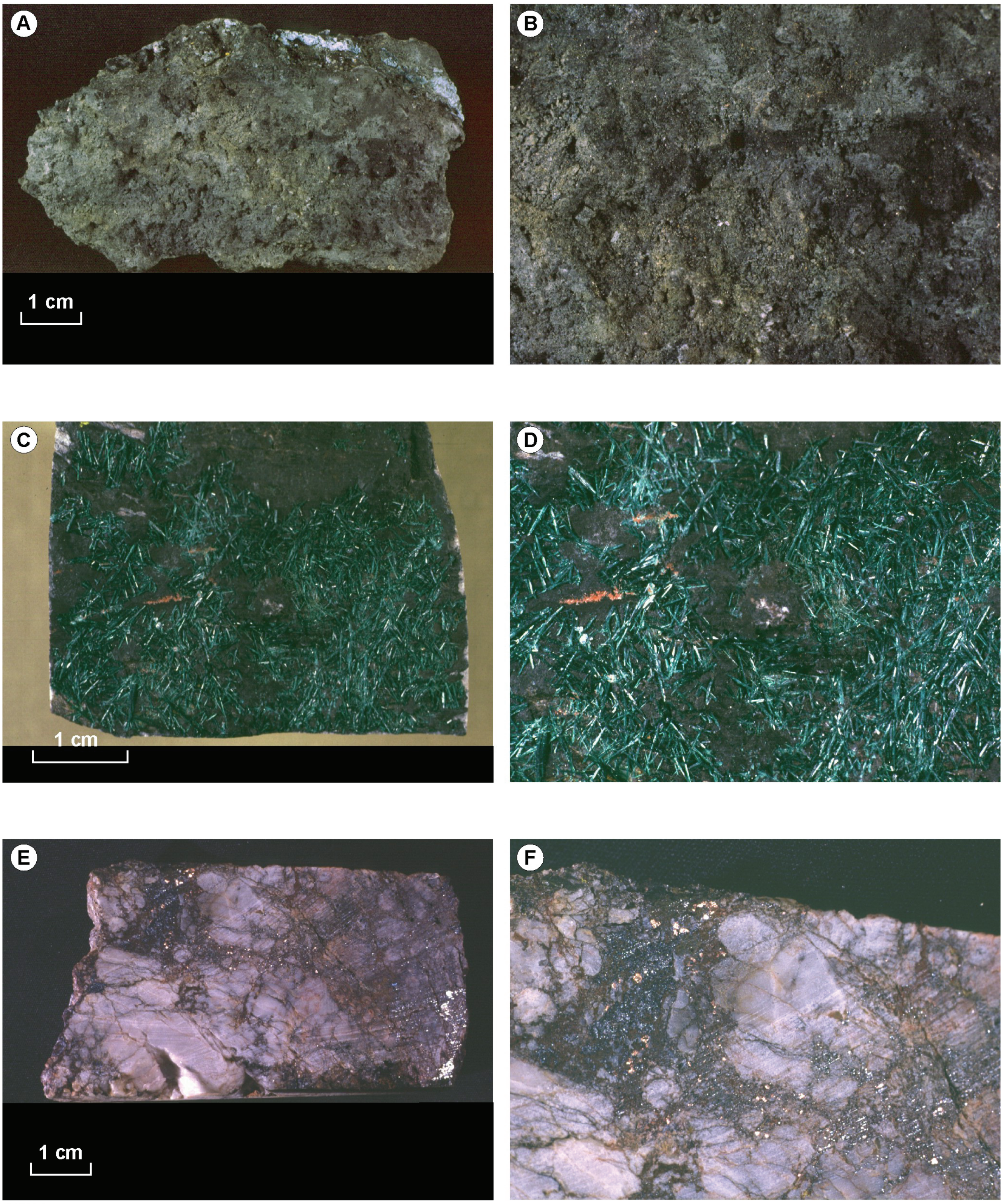
C. Acicular malachite infilling a fracture. This is typical of the form observed for malachite infilling fractures at New Cobar. Sample 138764. DD97NC0059 113 m.

D. Enlarged view of C.

E. Quartz vein material with infilling secondary chalcocite (black) and native copper (pink). This material has replaced primary Cu mineralisation close to the base of the oxidised zone. There is also some minor goethite. Sample contains 6.54% Cu, 2.7% S, 0.34% Pb and 390ppb Au. Sample 138834. DD97NC0059 127 m.

F. Enlarged view of part of E.

PLATE 9:



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8. SCANNING ELECTRON PHOTOMICROGRAPHS

PLATE 10: SEM IMAGES OF SUPERGENE GOLD

High fineness (>99.5% Au) gold with distinctive crystalline and irregular filigree forms and intergrown with colloform goethite and hematite has been observed in oxidised lode material from the New Cobar South open pit. This gold is interpreted as supergene in origin.

A. Polished section showing supergene gold aggregate (bright) intergrown with colloform Fe oxides/oxyhydroxides. Gold aggregate is ca 60 µm long and 7 µm wide. Backscattered electron image. Sample 138416. North end of New Cobar South open pit, 10 m from surface.

B. Section showing aggregates of supergene gold (bright) deposited in cavity in colloform iron oxides/oxyhydroxides. Large aggregate is ca 8 µm long. Backscattered electron image. Sample 138416. North end of New Cobar South open pit, 10 m from surface.

C. Separated supergene gold aggregate with highly irregular and delicate growth forms and some coarser crystalline gold. Aggregate is ca 110 µm long. Backscattered electron image. Sample 138416. North end of New Cobar South open pit, 10 m from surface.

D. Enlarged view of lower part of gold aggregate in C, showing crystalline gold with octahedral forms prominent. Note small, elongate growth impingement pits probably formed by bladed hematite. Secondary electron image.

E. Separated supergene gold aggregate showing wire-like shape and irregular crystalline forms. Aggregate is ca 100 µm long and 20 µm in diameter. Backscattered electron image. Sample 138416. North end of New Cobar South open pit, 10 m from surface.

F. Irregular and partly crystalline gold grain separated from gossanous lode material. Grain is ca 20 µm across. Backscattered electron image. Sample 138503. New Cobar South open pit, mineralised profile (P1),15.5 m from surface.

PLATE 10:

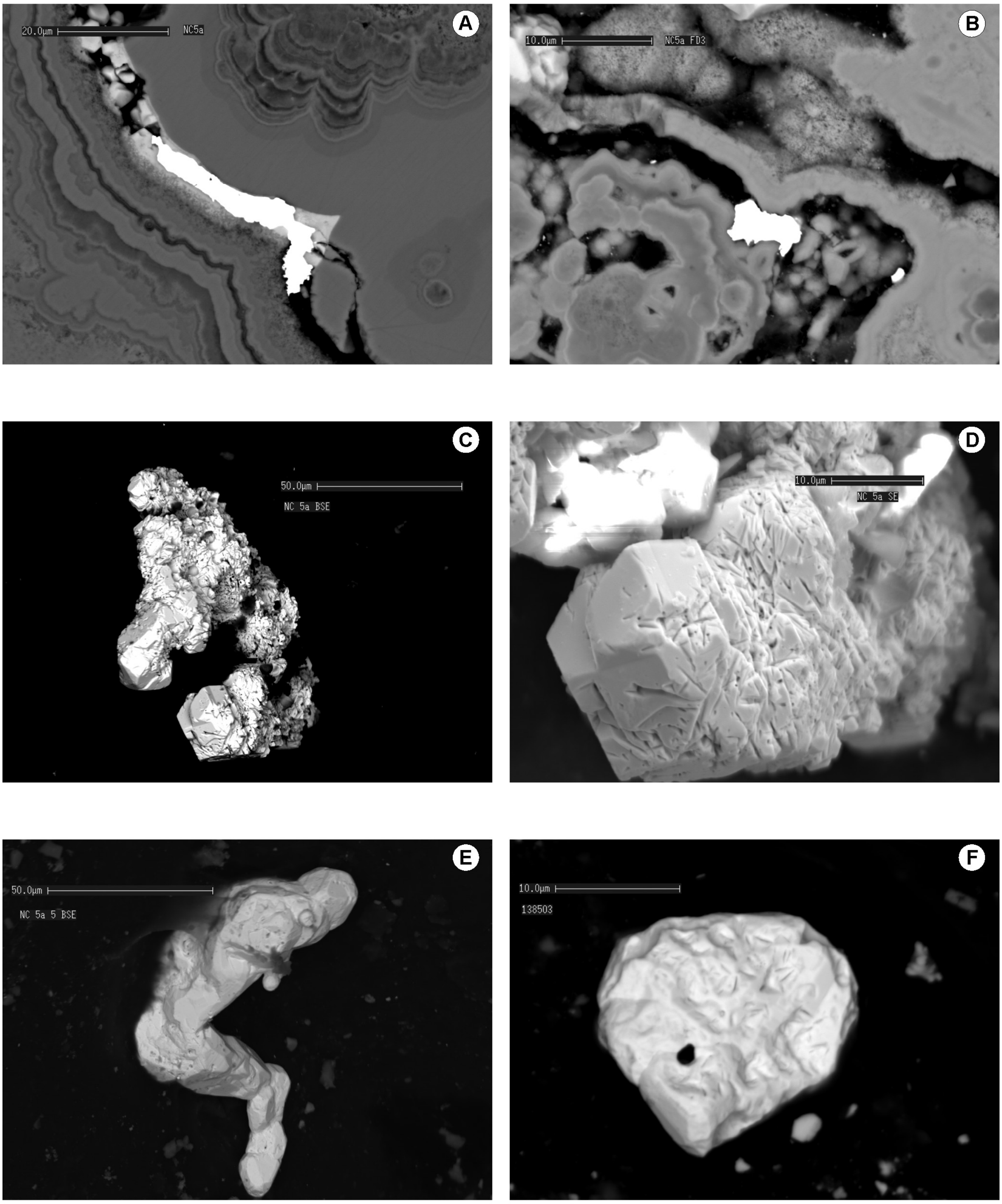

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PLATE 11: SEM IMAGES OF SOME SECONDARY OXIDE ZONE MINERALS

Some secondary minerals initially identified by X-ray diffraction analysis have been confirmed by qualitative energy dispersive analysis using a scanning electron microscope. Images of some of these minerals are included here to illustrate their small-scale growth habits and other features.

A. Copper-bearing lithiophorite showing tiny crystals making up botryoidal aggregates. Secondary electron image. Sample 138769. DD97NC0059 134 m.

B. Coronadite showing botryoidal growth form. Secondary electron image. Sample NC-16. New Cobar South open pit.

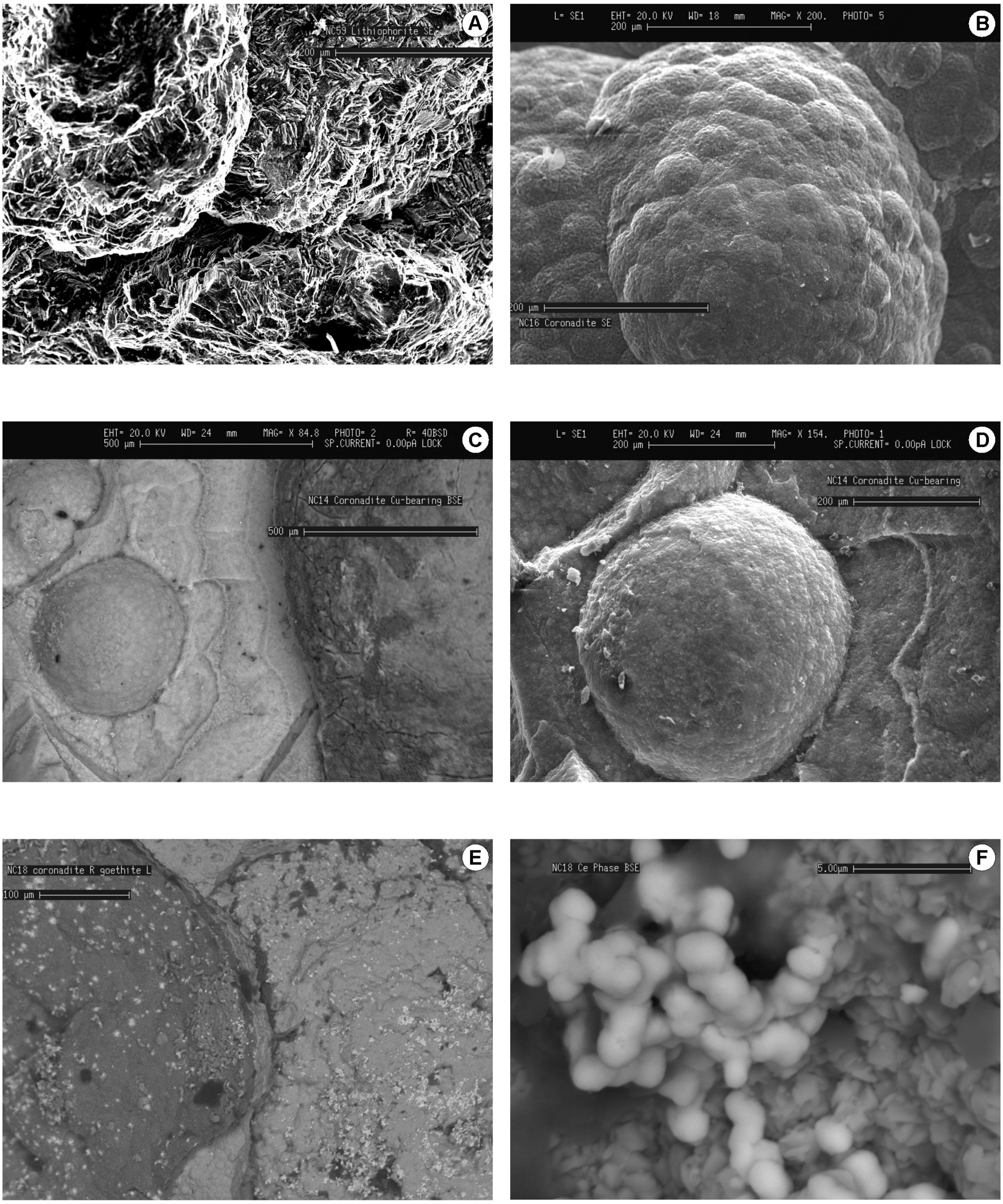
C. Coronadite (brighter area, left half of field) and santaclaraite (darker area at right). The coronadite area showed high Mn and Pb contents together with high Cu, Co and minor Ca, suggesting some intermixed phases. Note the botryoidal and fine-scale colloform growth features. Backscattered electron image. Sample NC-14. New Cobar South open pit.

D. Secondary electron image of part of C showing the layering of small coronadite crystals and potential for intermixed minerals. Sample NC-14. New Cobar South open pit.

E. Coronadite (lighter grey, right half of field) and goethite (dark area at left) The small bright grains and patches are a cerium mineral. Backscattered electron image. Sample NC-18. New Cobar South open pit.

F. Small aggregate of cerium mineral crystals (possibly bastnaesite or cerianite: see also Appendix 3). Individual crystals are ca 1.5 m across. This mineral probably accounts for the high Ce values recorded in some of the oxidised lode material. Backscattered electron image. Sample NC-18. New Cobar South open pit.

PLATE 11:



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APPENDIX I

A. Minerals Detected in the Weathering Zone of the New Cobar Deposit

Anglesite $PbSO_4$

Alunite-Jarosite Group (Plumbogummite) $PbAl_3H(PO_4)_2(OH)_6$
(Hinsdalite) $PbAl_3(PO_4)(SO_4)(OH)_6$

Chalcanthite $Cu^{2+}SO_4 \bullet 5H_2O$

Chalcocite Cu_2S

Copper Cu

Coronadite ideally $Pb(Mn^{4+},Mn^{2+})_8O_{16}$

Covellite CuS

Cryptomelane ideally $K_2(Mn^{4+},Mn^{2+})_8O_{16}$

Goethite $Fe^{3+}O(OH)$

Halite NaCl

Hematite $\propto$-Fe_2O_3

Hollandite ideally $Ba(Mn^{4+},Mn^{2+})_8O_{16}$

Kaolinite $Al_2Si_2O_5(OH)_4$

Lithiophorite ideally $(Al,Li)Mn^{4+}O_2(OH)_2$

Maghemite γ-Fe_2O_3

Magnetite Fe_3O_4

Malachite $Cu^{2+}{}_2(CO_3)(OH)_2$

Opaline silica $SiO_2 \bullet nH_2O$

Pyromorphite $Pb_5(PO_4)_3Cl$

Ramsbeckite ideally $(Cu^{2+},Zn)_{15}(SO_4)_4(OH)_{22} \bullet 6H_2O$

Santaclaraite $CaMn^{2+}{}_4Si_5O_{14}(OH) \bullet H_2O$

B. Important Secondary Mineral Hosts for Elements in the New Cobar Profile

(minerals for which the element is an essential constituent shown in bold)

As: Fe oxides/oxyhydroxides

Ba: hollandite

Bi: Fe oxides/oxyhydroxides

CO_3: malachite

Cu: chalcocite, native Cu, chalcanthite, malachite, ramsbeckite, **covellite**
Fe oxides/oxyhydroxides, Mn oxides, alunite -jarosite minerals

Mn: coronadite, lithiophorite, hollandite, santaclaraite

P: pyromorphite, plumbogummite, hinsdalite,
Fe oxides/oxyhydroxides

Pb: anglesite, coronadite, pyromorphite, plumbogummite, hinsdalite,
Fe oxides/oxyhydroxides

S: chalcocite, anglesite, chalcanthite, hinsdalite, Fe oxides/oxyhydroxides

Se: Fe oxides/oxyhydroxides

W: Fe oxides/oxyhydroxides

Zn: ramsbeckite, Fe oxides/oxyhydroxides, Mn oxides, alunite-jarosite minerals

APPENDIX II

X-ray Diffraction Analyses

Minerals identified by XRD are grouped into major, minor and trace components based on major peak intensity. This technique gives approximate abundance only. Minerals with ? are uncertain due to some peak overlaps or very low peak intensity.

Sample NC-10(a): black/brown botryoidal mineral
Major minerals: goethite
Minor minerals: quartz
Trace minerals: hematite, maghemite, Mn oxide

Sample NC-10(b): white coating mineral
Major minerals: kaolinite
Minor minerals: goethite
Trace minerals: quartz, mica

Sample NC-11: black oxide coating
Major minerals: hematite, goethite
Minor minerals: quartz, kaolinite
Trace minerals: n/a

Sample NC-12: pink/white mineral
Major minerals: kaolinite
Minor minerals: quartz
Trace minerals: goethite

Sample NC-13(a): botryoidal mineral
Major minerals: goethite
Minor minerals: hematite, coronadite
Trace minerals: quartz, alunite-jarosite?

Sample NC-13(b): light brown coating on botryoidal mineral (NC-13(a))
Major minerals: goethite
Minor minerals: hematite, coronadite
Trace minerals: quartz, kaolinite

Sample NC-14: lustrous grey-brown mineral coating
Major minerals: Mn Oxide - santaclaraite
Minor minerals: quartz
Trace minerals: goethite

Sample NC-15: pale blue thin coating
Major minerals: kaolinite
Minor minerals: quartz, mica, goethite
Trace minerals: opal?

Sample NC-16: grey mineral forming bands on black mineral surface
Major minerals: Mn Oxide - hollandite, coronadite
Minor minerals: cryptomelane?
Trace minerals: quartz, goethite

Sample NC-17: bluey-black irredescent coating
Major minerals: goethite
Minor minerals: hematite, opal?
Trace minerals: rutile?

Sample NC-18(a): white mineral
Major minerals: kaolinite
Minor minerals: n/a
Trace minerals: goethite, quartz

Sample NC-18(b): black-green iridescent oxide mineral
Major minerals: hematite, goethite, Mn Oxide - hollandite/coronadite
Minor minerals: quartz, kaolinite
Trace minerals: cryptomelane?

Sample NC-19: green acicular mineral
Major minerals: malachite
Minor minerals: quartz, hematite
Trace minerals: mica?

Sample NC-20: thin blue mineral coating
Major minerals: kaolinite
Minor minerals: quartz, halite
Trace minerals: goethite, mica

Sample NC-21: white powdery mineral
Major minerals: kaolinite
Minor minerals: quartz, goethite
Trace minerals: n/a

Sample 138521: P2 - 4.9m: steely grey mineral
Major minerals: goethite, cryptomelane/coronadite/coronadite
Trace minerals: maghemite?
Trace minerals: hematite?

Sample 138833 (a): DD97NC0059 - 48.5m: black powdery material
Major minerals: magnetite
Minor minerals: chlorite, quartz
Trace minerals: hematite, goethite, kaolinite

Sample 138833 (b): DD97NC0059 - 48.5m: pale blue/white phase
Major minerals: chalcanthite
Minor minerals: gypsum?, magnetite
Trace minerals: quartz

Sample 138747(a): DD97NC0059 - 49m: white coating mineral
Major minerals: kaolinite
Minor minerals: quartz
Trace minerals: mica, hematite/goethite

Sample 138747(b): DD97NC0059 - 49m: black coating
Major minerals: lithiophorite
Minor minerals: quartz
Trace minerals: kaolinite?

Sample 138749: DD97NC0059 - 56m: black coating mineral
Major minerals: lithiophorite
Minor minerals: quartz
Trace minerals: n/a

Sample 138764: DD97NC0059 - 113m: green acicular mineral
Major minerals: malachite
Minor minerals: quartz
Trace minerals: n/a

Sample 138765: DD97NC0059 - 118m: green acicular mineral
Major minerals: malachite
Minor minerals: quartz
Trace minerals: kaolinite, albite?

Sample 138834: DD97NC0059 - 127m: native copper and chalcocite
Major minerals: copper
Minor minerals: chalcocite
Trace minerals: quartz, covellite?

Sample 138769(a): DD97NC0059 - 134m : black crusty material
Major minerals: lithiophorite
Trace minerals: kaolinite

Sample 138769(a): DD97NC0059 - **134m** : white phase
Major minerals: kaolinite
Minor minerals: quartz
Trace minerals: hematite/goethite, lithiophorite

Sample 138697: DD97NC0060 - 42m: black penetrating mineral
Major minerals: lithiophorite
Minor minerals: quartz, mica, chlorite
Trace minerals: kaolinite, feldspar, goethite?

Sample 138704(a): DD97NC0060 - 84m: brown mottle -dark zone
Major minerals: hematite
Other minerals: quartz, mica, chlorite, kaolinite, feldspar
Trace minerals: pyrite

Sample 138704(b): DD97NC0060 - 84m: brown mottle -light zone

Major minerals:	goethite
Minor minerals:	quartz, mica, chlorite, kaolinite, feldspar
Trace minerals:	hematite, pyrite

APPENDIX III

SEM Investigations

Sample NC-14 (lustrous grey-brown mineral coating)

Two distinct phases were identified.

1. Cu- and Co-bearing Pb manganese oxide. This may represent a mixture of a Cu-Co-rich Mn oxide and coronadite. The coronadite appears to be developed at a different, lower level (in a different layer) in the sample and is the steely grey mineral seen in hand specimen.
2. Ca-rich manganese silicate containing Fe, Al and K. XRD suggests santaclaraite (Appendix II). This material appears to correspond to the reddish-brown mineral seen in hand specimen. It needs further characterisation.

Sample NC-16 (grey mineral forming bands on black mineral surface)

Coronadite was confirmed as a major mineral (it is the main phase coating the sample). This is the normal Pb end member, but possibly with some Al. XRD indicates coronadite as a major phase.
Also observed were small aggregates of a Ce mineral on the coronadite. This appears to be a near pure Ce phase (possibly a carbonate or oxide: see also Plate 11).

Sample NC-18 (black-green iridescent oxide mineral)

Detected coronadite (Pb end member). Small aggregates of the Ce mineral were observed coating the coronadite and Fe oxide. XRD indicates hematite, goethite and coronadite as major minerals.

Sample 138769 (DD97NC0059 134 m)(black and lustrous crusty material)

Detected abundant lithiophorite with a high Cu content. Also detected small grains of a Pb mineral, possibly mimetite, as well as other specks of high atomic number minerals. XRD indicates lithiophorite. Sample requires electron microprobe work to quantify Cu content.

NOTES