The application of geophysics in the discovery of brownfields' copper mineralisation at Jervois, Northern Territory

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Introduction

KGL Resources Limited (KGL) is a Brisbane-based, ASX-listed (ASX:KGL) company focused on the development of the Jervois polymetallic mineral deposits located in the Northern Territory of Australia, ~386 km by road, east-northeast of Alice Springs (**Figure 1**). The potentially exploitable metallic minerals at Jervois include copper, silver, gold, lead, zinc, cobalt and tungsten. The initial focus for KGL is the mining of copper ores and the processing and marketing of copper concentrates also containing payable silver and gold by-products.

KGL is the 100%-holder of four mineral leases and two exploration licences that comprise the Jervois Project (**Figure 2**).

The main site activities for KGL during 2021 have been drilling for expansion and improved definition of the mineral resources at three main deposits, namely Reward, Bellbird and Rockface. The combined Mineral Resources for the deposits have been defined as 22.65 Mt at 2.04%

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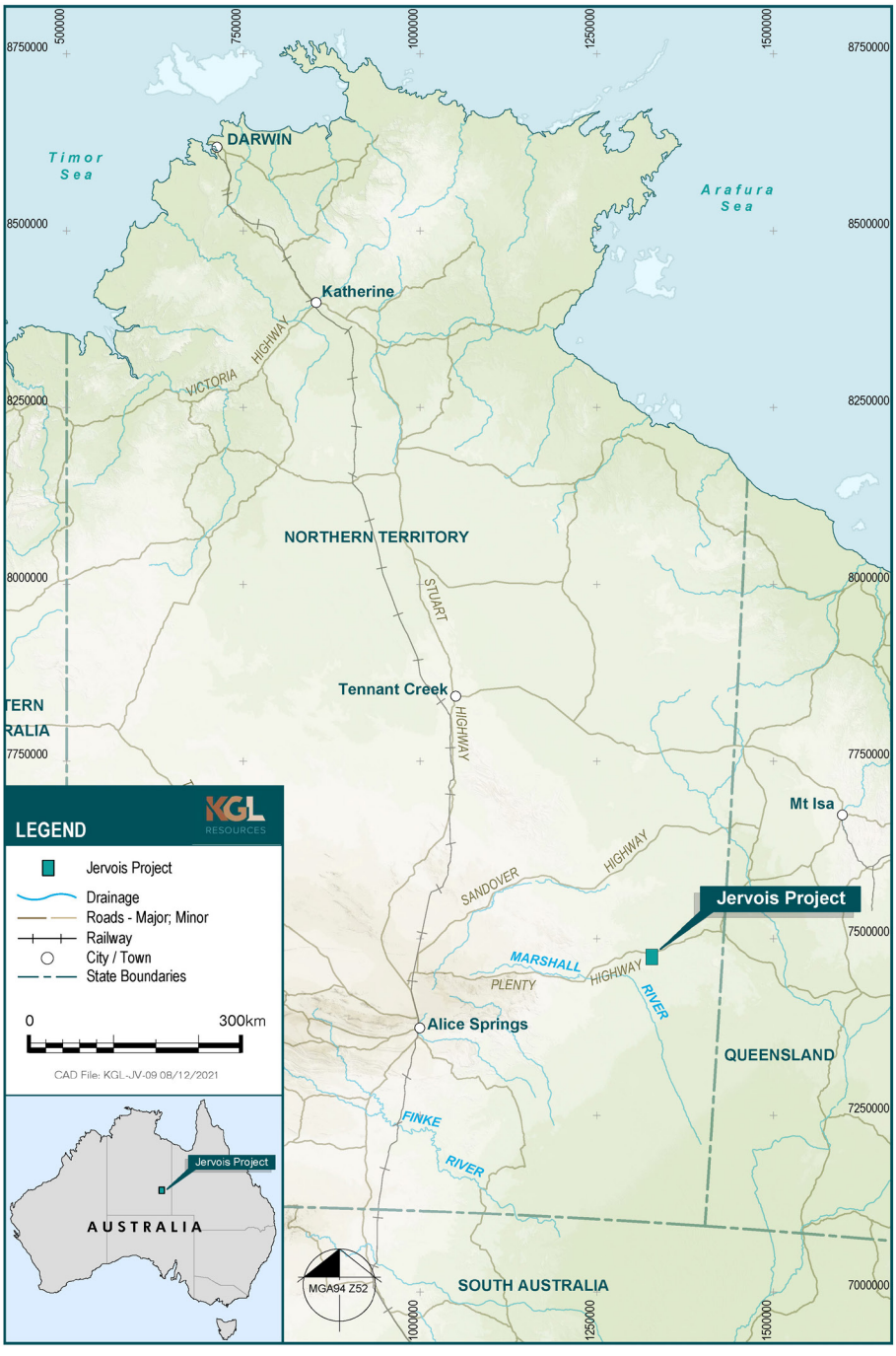

Figure 1. Location of copper–silver–gold Jervois Project.

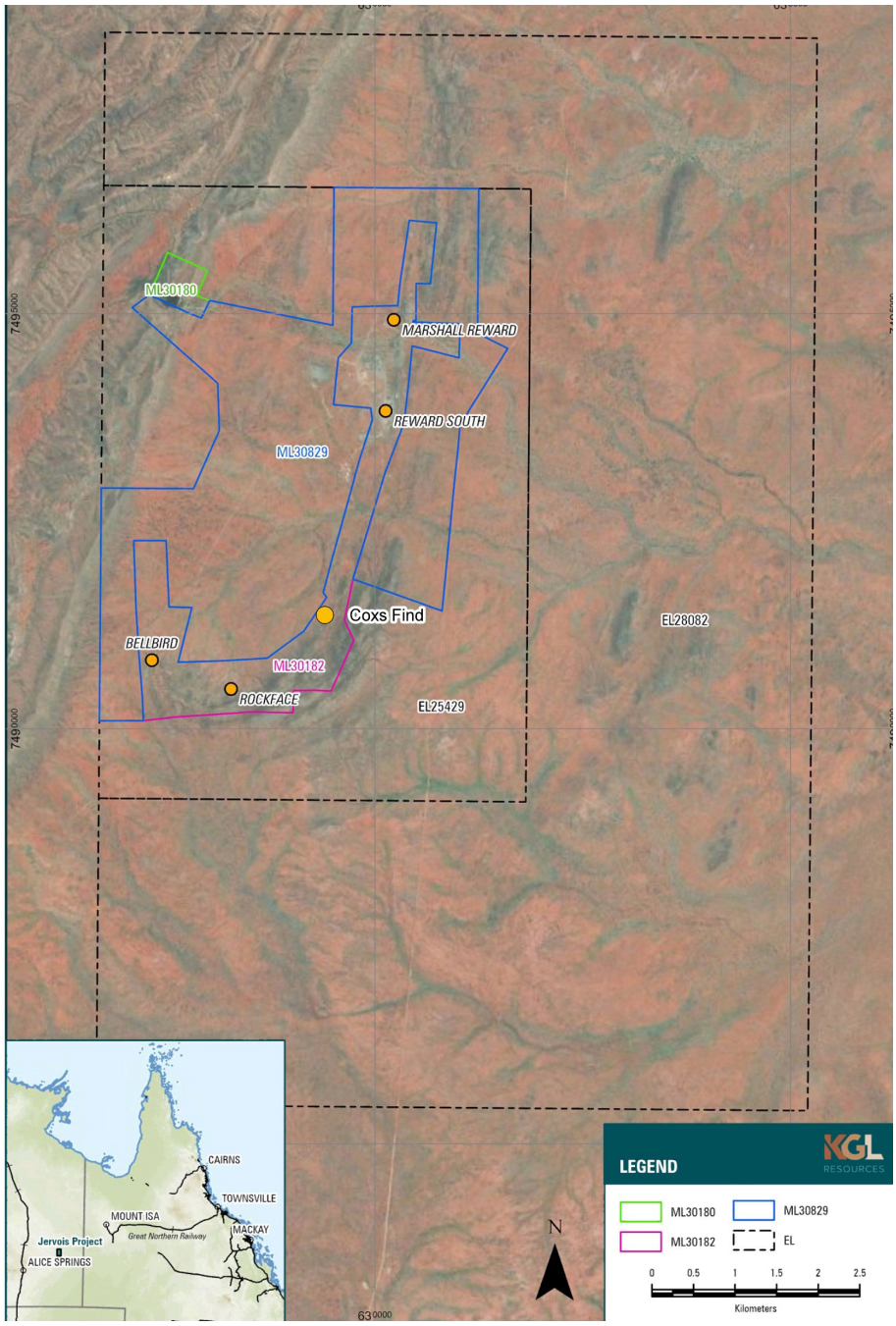

Figure 2. Jervois Project mineral tenements and location the major deposits and Cox's Find prospect.

Cu, 25.5 g/t Ag and 0.26 g/t Au (JORC 2012 Indicated and Inferred categories) containing 461 600 t of copper, 18.54 Moz of silver and 186 800 oz of gold (KGL 2020, 2022a, b). These resource figures represent a 12.6% increase in contained copper over the previous mineral resource estimate published in 2020.

KGL has also undertaken further exploration at Jervois, including a large MIMDAS induced polarisation–resistivity (IP) survey, down-hole electromagnetic surveys (DHEM) and drilling of selected targets.

Drilling recommenced at Jervois on 16 February 2021 after a Covid-19 enforced hiatus of nearly 12 months. A total of 86 holes were completed during the year for an advance of 29 117 m. Of this total, 10 holes (4769 m) can be classified as exploration drilling, with the remainder as resource growth and definition drilling.

This paper presents a case study of the exploration of a known and previously drilled copper occurrence at Cox's Find and the geophysics-led discovery of significant copper at Cox's Find South.

Geological and exploration setting

The regional geological setting of the Jervois Project is described extensively by Mayes (2017). The project lies in the far eastern part of the Aileron Province in the Arunta Region, which forms the southern portion of the North Australian Craton (**Figure 3**).

The sedimentary and volcanic rocks of the Jervois area date at ca 1800 Ma and have been metamorphosed to amphibolite–upper amphibolite facies, probably at ca 1720–1700 Ma. The host rocks to the mineralisation

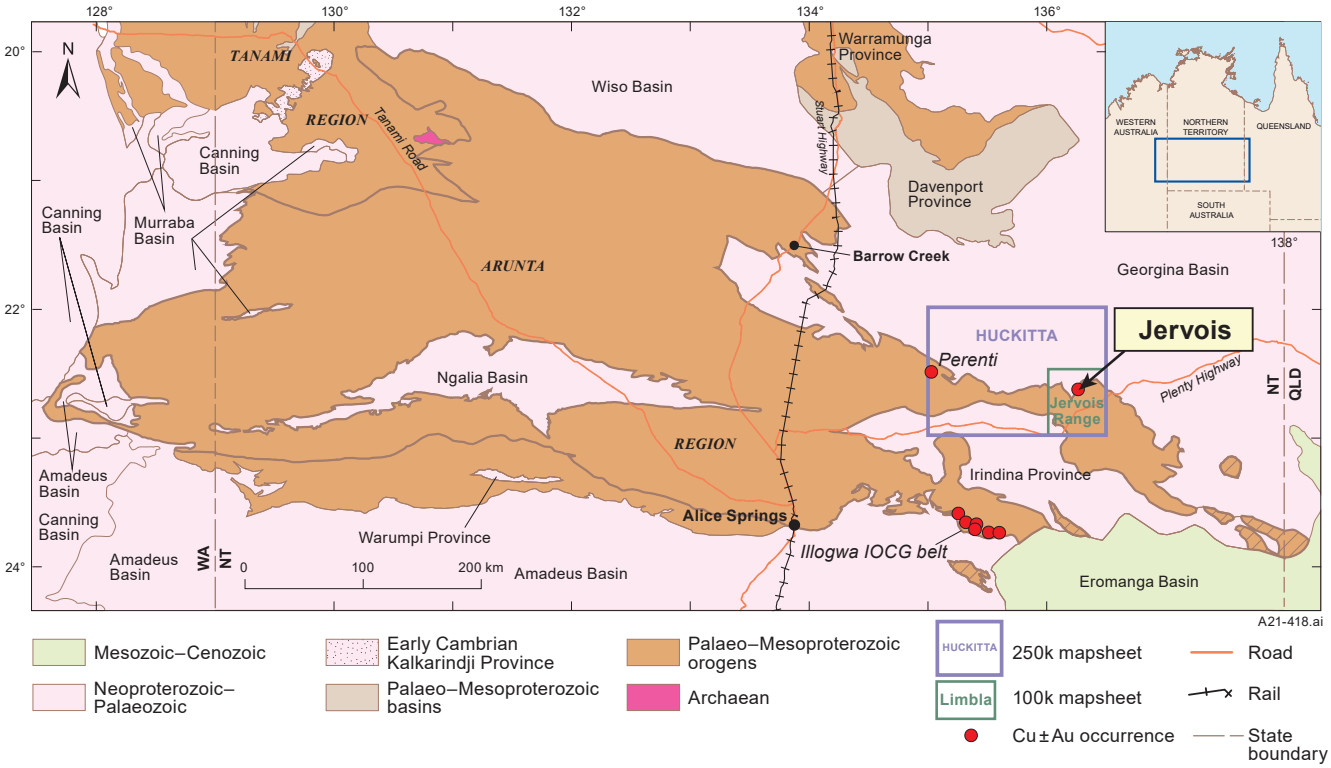

Figure 3. Regional geological setting of Jervois.

are the Bonya Schist, which comprises predominently psammitic-siltstone-pelites and associated felsic igneous rocks.

The Jervois sequence is folded and the western limb is truncated by a large fault resulting in younger Georgina Basin rock being juxtaposed on the Jervois sequence. The result is the large, well-known 'J-fold', which is readily observed in satellite imagery and aerial photographs (**Figure 4**).

Morgan (2021) showed that Rockface, Reward and Bellbird, which are currently considered the major mineral deposits at Jervois (**Figure 4**), are generally stratabound and hosted within the rocks that form the J-fold. These metasedimentary rocks typically present, with varying mineral content, as garnet-chlorite-magnetite schist. Laterally they can include quartz tourmaline and banded epidote and calc-silicate rocks.

Exploration over the last four years has shown that there are two styles of mineralisation at Jervois: lower grade syn-depositional or stratabound disseminated sulfide mineralisation, and higher grade structurally-controlled mineralisation. The latter can occur in shoots and may represent remobilised stratabound mineralisation. The orientation of the shoots varies, with the Rockface mineralisation dipping 80° north, while on the western and eastern limbs of the J-fold at Bellbird and Reward respectively, the shoots are essentially vertical (Morgan 2021).

Figure 4 shows that in addition to the major known deposits, a plethora of copper occurrences have been found along the J-fold, many of which are yet to be explored in any detail. Better understanding of the both the structural setting and the clear geophysical fingerprint of the known deposits has provided compelling incentives for exploring these occurrences using both IP and DHEM. One such an occurrence that was explored is Cox's Find and this paper presents the results of that program.

The earliest reference found to Cox's Find is a map by WA Robertson entitled 'Cox's Copper Deposits, Jervois Range, Northern Territory (July 1958)'. Robertson mapped a sequence of quartz schists and quartz granulite, including a staurolite unit, and recorded 'visible copper mineralisation' and 'copper lode >3%'. **Figure 5** shows a picture of the shallow historical prospect workings at Cox's Find.

Since the first mapping and prior to 2021, 21 drillholes totalling 1988 m of mostly RC were completed with limited success. **Figure 6** shows the location of previous drilling at Cox's Find. Three drillholes intersected some significant mineralisation (**Table 1**; KGL 2013).

MIMDAS method and its application at Jervois

The choice of the MIMDAS method was based on a 2020 review of the historical geophysical data in the Jervois region (Hine 2021). This included historical Orion 3D IP, airborne EM, surface and DHEM, magnetics, gravity, and very early generation MIMDAS data. The review highlighted the fact that strong chargeability anomalies are produced by the Rockface Main lens, Bellbird lenses, Reward and Cox's deposits; the only exception is the Rockface North lens, which was not resolved. Modelling shows that the Rockface North lens, which does not have a large sulfide alteration halo, is too small to be detected at great depth by surface IP.

The 2020 review also showed that surface EM was only truly effective for the Rockface Main lens and parts of the Reward deposit (specifically the Reward Deep South lens). Most of the other lenses, although containing quite high-grade copper mineralisation, were only weakly conductive (5–50 Siemens) and thus could only be detected

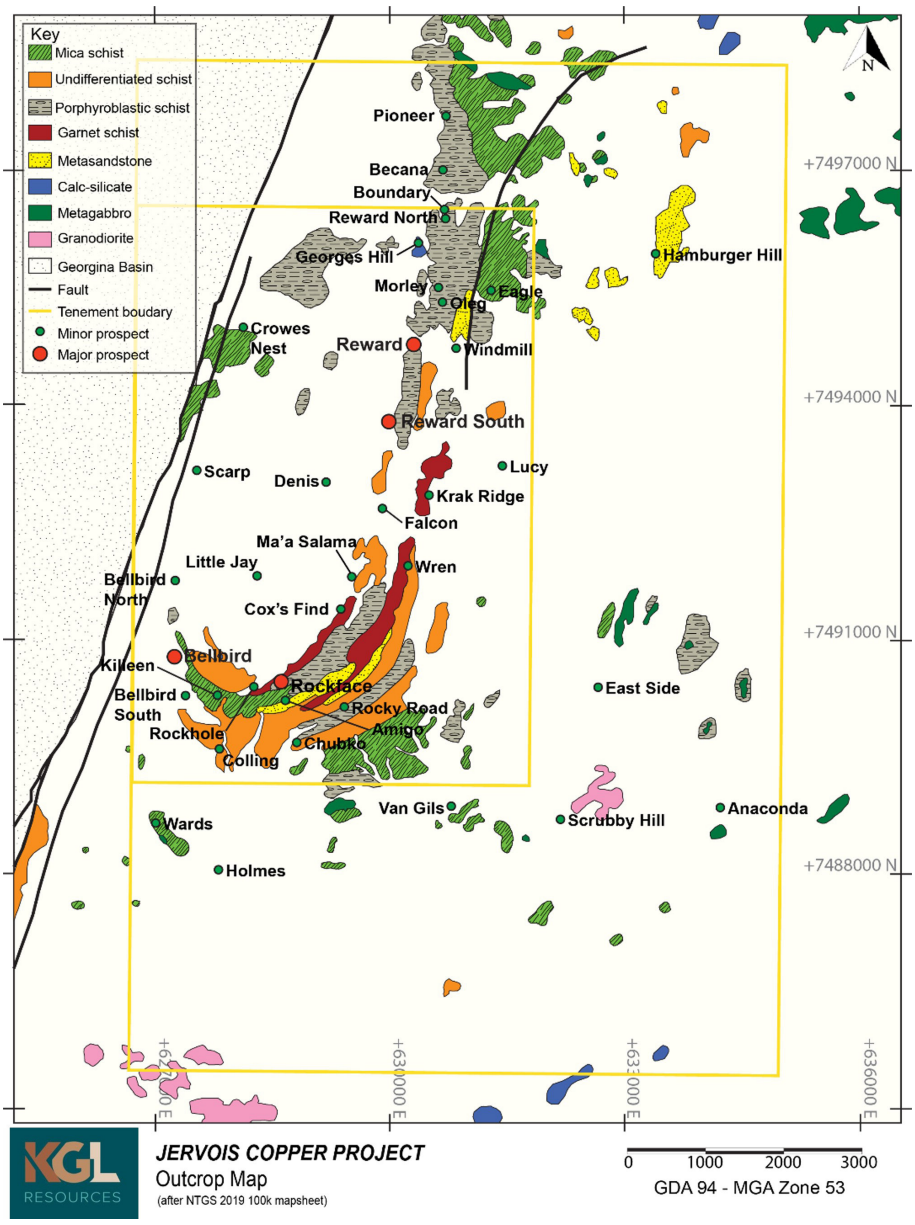

Figure 4. Outcrop map showing the 'J-fold' and the many copper occurrences at Jervois.

when very close to surface. This limits the usefulness of surface EM or airborne EM, but not DHEM (see next section).

Overall, IP was considered a more effective exploration tool because it could detect both low and high conductance targets.

Figure 5. Copper mineralisation in shallow workings at Cox's Find.

The Jervois MIMDAS survey was carried out by contractors GRS Pty Ltd in June 2021, with survey design and data interpretation by geophysicist Kate Hine of Mitre Geophysics Pty Ltd. The Cox's Find portion comprised nine north-northwest-oriented lines of 'true 3D' IP and four northwest-oriented lines of 2D IP. The 3D data were acquired in sets of 3 lines, spaced at 250 m with electrodes spaced at 100 m laid out along each line (3D multi pole-dipole geometry) with transmitter points in between the electrodes on each line. The 2D lines were also spaced 250 m and used 100 m electrode separation.

The data were modelled primarily in UBC[3]. Several models were run to test the robustness of the various features and allow qualitative estimate of the depth of investigation. One ambitious model was even attempted to incorporate 2014 Orion data but this failed to give any meaningful results, possibly because the inversion 'pays more attention' to numerically overwhelming (40 000) Orion data points at the expense of fitting the minority (8000) MIMDAS data points.

[3] University of British Columbia inversion modelling computer program

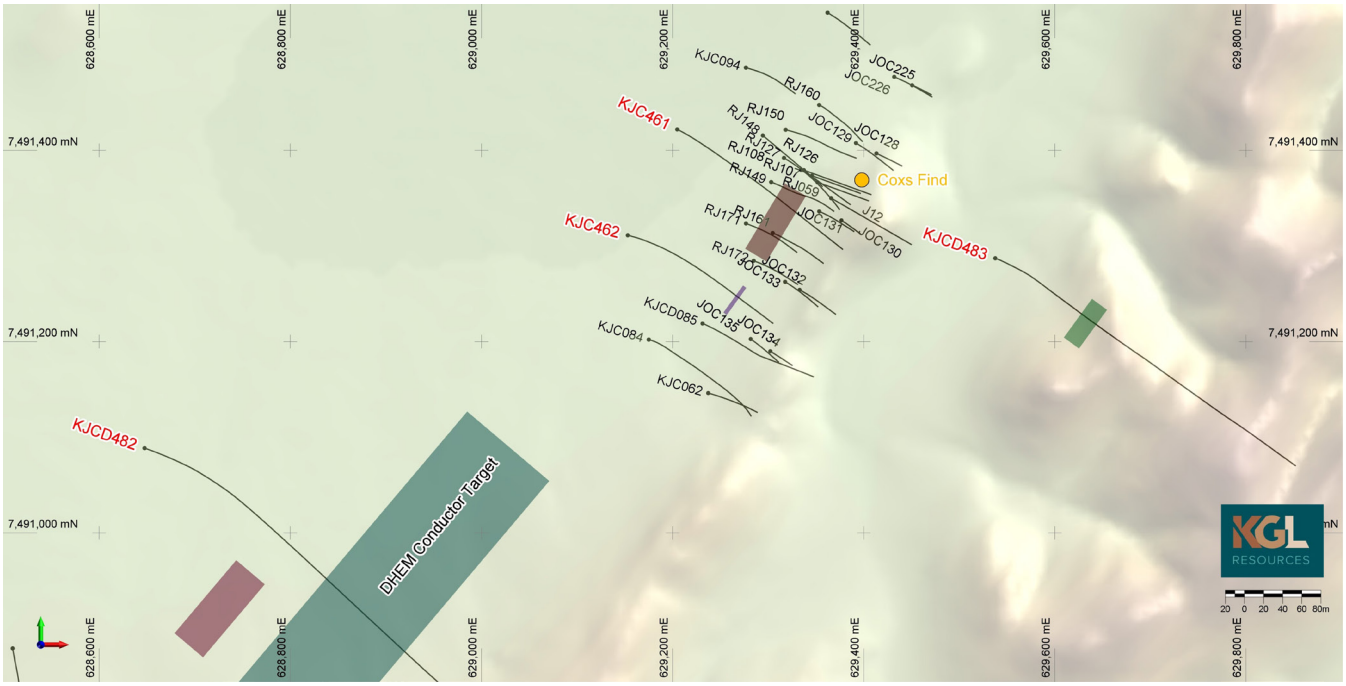

Figure 6. Location of drilling at Cox' Find. KGL 2021 holes (red labels); previous holes (black labels); DHEM conductors (rectangles); topography (background image).

Table 1. Significant mineralisation was found in three drillholes out of twenty-one in previous in drilling at Cox's Find.

Drillhole	From (m)	To (m)	DH length (m)	Cu%
JOC131	55	57	2	2.16
KJC062	68	71	3	2.57
KJCD085	128	130	2	6.47

DHEM method and its application at Jervois

Over 150 holes have been surveyed with DHEM at the Jervois Project. DHEM often works where surface EM does not because DHEM has much lower noise sensitivity and its receiver is much closer to the target whilst simultaneously being much further from any interfering overburden signal. The 2020 geophysics review highlighted that DHEM is effective for both detecting and delineating the mineralisation at Bellbird, Reward, and particularly at Rockface. One notable feature is the large variation in mineralisation conductance. At Bellbird, the mineralisation typically models as about 5–35 Siemens (S) conductance, ie very weak conductance. At Rockface, the conductance ranges from 100–500 S, ie moderate to strong conductance. Some parts of Reward (eg Reward Deep South) have similar conductance to Rockface, but the majority of Reward is similar to Bellbird.

Unlike IP, which responds to the bulk surface area of (primarily) disseminated sulfides, DHEM detects only interconnected (more massive) sulfides. This ability to discriminate disseminated sulfides from more-massive sulfides means that DHEM is a very reliable tool at Jervois for establishing the size, geometry and location of lenses associated with particular drillhole intersections, as well as the location, size and geometry of any 'near-miss' lenses. In the case of drilling IP anomalies, DHEM can help confirm whether any particular zone of disseminated mineralisation is likely to have an associated higher-grade core.

IP survey results at Cox's Find

The main MIMDAS geophysical feature in the Cox's Find South is a broad, strike-extensive chargeability anomaly. The anomaly is over 1.5 km long and extends between Rockface at its southwestern end to Cox's Find at its northeastern end (**Figure 7**). There is also a small and localised chargeability anomaly associated with the mineralisation at Cox's Find itself, plus a strong response at the very southwestern end due to the effect of Rockface, which is partly outside the survey area.

Initial drill testing and results

Drillhole KJCD482 was drilled to test the IP chargeability anomaly at a position ~400 m below surface and 500 m southwest of the Cox's Find outcrop (**Figures 7** and **8**). The hole intersected two broad zones of weakly disseminated sulfide mineralisation composed of mainly pyrite and chalcopyrite. The upper zone is 60 m thick, from 471–531 m downhole, and averaged 0.5% S and 0.15% Cu. The lower zone is 98 m thick, from 645–743 m downhole, and assayed 0.6% S and 0.04% Cu. Empirically, the large volume of disseminated copper and iron sulfide implied by these results was considered to adequately explain the IP anomaly.

From 523 m, within the upper zone, is a 3 m downhole intersection of more intensely disseminated and thin stringer-vein style chalcopyrite and bornite mineralisation. The host lithology is biotite-muscovite meta-psammopelite. Silicification is the main alteration phase with localised garnet development (**Figure 9**). Localised alteration of biotite to chlorite occurs along with late-stage magnetite to hematite (**Figure 10**). K-feldspar/scapolite alteration is observed along fractures, and carbonate veinlets cross-cut all other alterations styles.

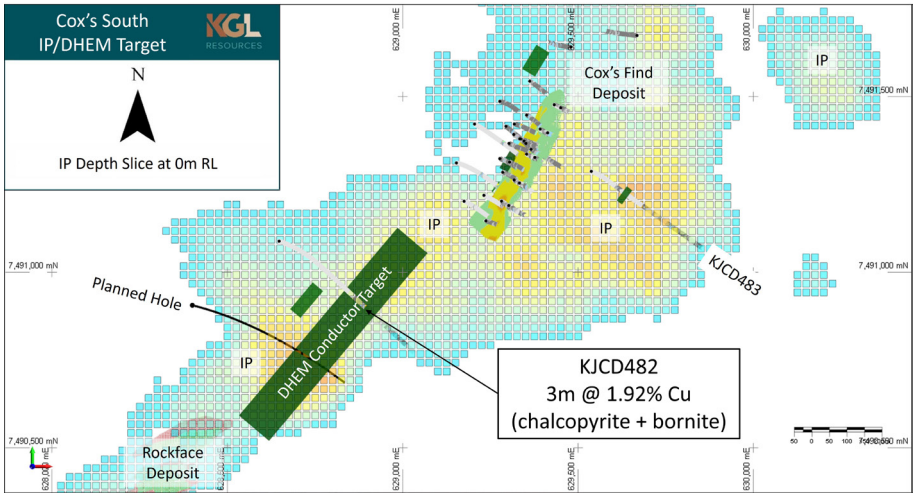

Figure 7. IP depth slice at 0 m RL of Cox's South target showing the large IP anomaly (coloured blocks, warmer colours higher chargeability) along strike to the southwest from Cox's Find prospect. Drilling is depicted as grey traces; planned drillhole as a black trace. The large conductor plate from KJCD482 is the dark green rectangle. Other smaller conductors (smaller green rectangles) are evident from KJC461, KJC462 and KJCD483, but these are not considered priority targets.

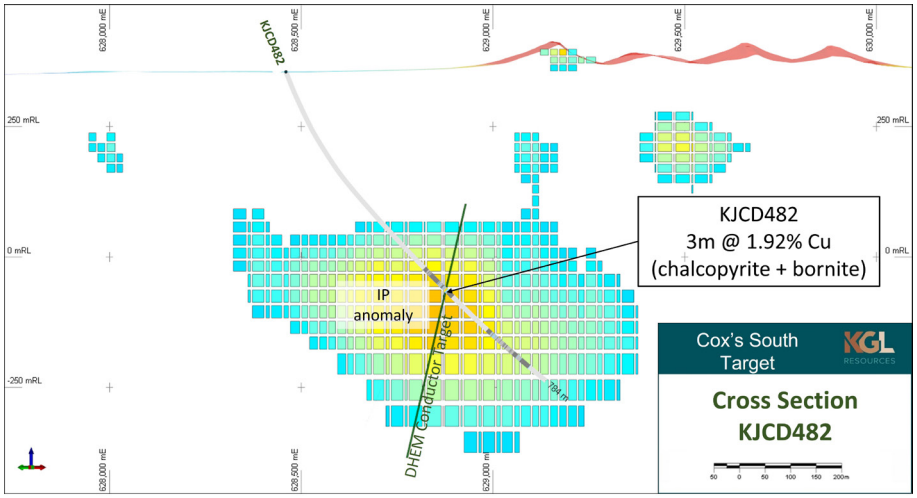

Figure 8. Cross section of Cox's South discovery hole, KJCD482 showing MIMDAS IP anomaly (coloured blocks, warmer colours higher chargeability) and the DHEM conductor target. A follow-up hole will be drilled to target the conductor ~200 m along strike to the southwest.

Mineralisation is multiphase with disseminated sulfides, dominantly pyrite, pervasive throughout the entire interval (**Figure 11**). Both pyrite and chalcopyrite occur as localised foliation-controlled mineralisation (**Figure 12**). Chalcopyrite and bornite appears as late cavity-fillings in syn-deformational quartz veins (**Figure 13**). Post-deformational carbonate veinlet mineralisation is mostly bornite and chalcopyrite (**Figure 13**). Post-deformational brecciated quartz vein mineralisation appears as porphyroclasts of earlier veins and host rocks (**Figure 14**). Collectively the late-stage veining and

Figure 9. Quartz vein with localised micro garnet (Gr) alteration, with a thin diffuse carbonate-feldspar (Ca-K) veinlet.

Figure 10. Localised alteration, showing Biotite (Bi) to chlorite (Ch) and magnetite (Mt) to hematite (He).

Figure 11. Disseminated pyrite (Py_DS) and (S2) foliation-controlled pyrite.

Figure 12. Post S2 deformational quartz vein (Qv) with chalcopyrite (Cp) and foliation-controlled (S2) chalcopyrite and pyrite mineralisation (FC_Cp-Py).

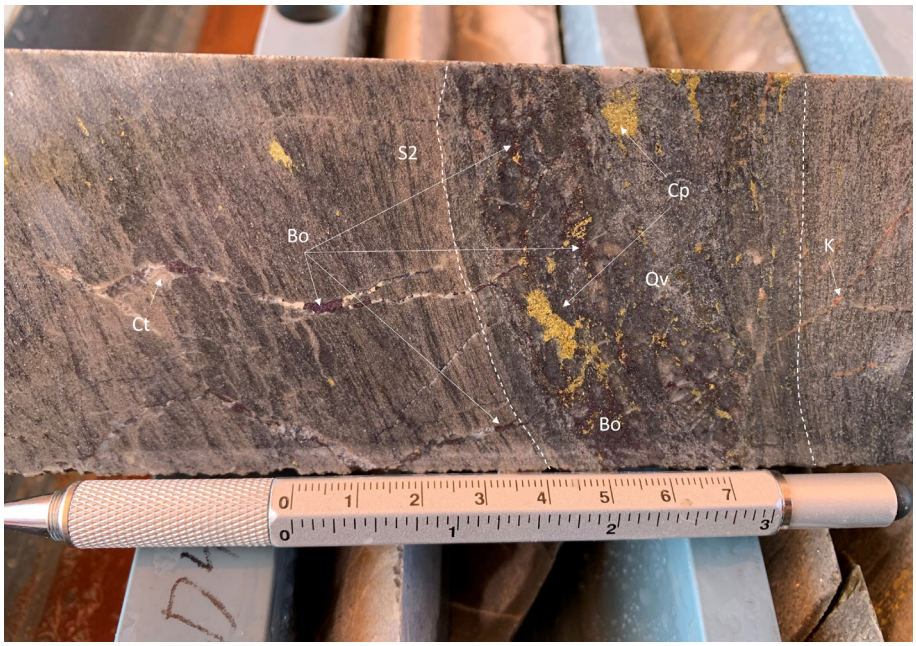

Figure 13. Photo is of drill core from KJCD482 showing syn deformational quartz vein (Qv) with chalcopyrite (Cp) and bornite (Bo) cavity-filling parallel to the S2 foliation (centre of the photo). A carbonate veinlet (Ct, left side of photo) hosts bornite and cross-cuts the Qv vein. K-spar/scapolite (K) alteration evident along the fracture toward the right of photo.

Figure 14. Post deformational brecciated quartz vein. Pyrite (Py) chalcopyrite (Cp). Porphyroclasts containing chalcopyrite and pyrite.

alteration styles are considered evidence for the existence of massive sulfide shoots in the vicinity of hole KJCD482.

Assays returned a copper grade of 1.92% over the 3 m interval along with 14.7 ppm Ag (KGL 2021).

Another hole, KJCD483, was drilled to test a broad modelled IP response ~350 m southeast of the Cox's Find outcrop. The hole intersected weakly disseminated pyrite and chalcopyrite mineralisation as well as encouraging alteration over broad zones, which likely explains the IP anomaly. One interval of 2.53% Cu was intersected in KJCD483 over a downhole interval of 1.14 m from 234.11 m.

DHEM survey results at Cox's Find

Down hole electromatic surveys were carried out in 16 holes at Jervois during 2022 (**Figure 15)**. Significant DHEM conductors typically associated with copper mineralisation were detected at Cox's South IP anomaly (KJCD482), Rockface (KJCD481D3 and KJCD481D4), Rocky Road/ Rockface East (KJCD485) and Reward.

DHEM on KJCD482 showed a very large, but low conductance response centred at 525 m downhole. The response is a positive axial component anomaly extending from 350–700 m downhole, and a cross over in the U and V component. The hole was surveyed twice: once with a B-field digi-Atlantis, and a second time with the BH43 coil probe. Coil probes are generally better at mapping weak anomalies, and this is certainly true from the KJCD482 response.

Modelling of the anomaly indicated a 700 × 500 m (very approximate dimensions), very low conductance source (2S), steeply northwest dipping (77° towards 310°). The centre of the source is southwest of the KJCD482. This correlates well with the IP, which also increases in strength towards

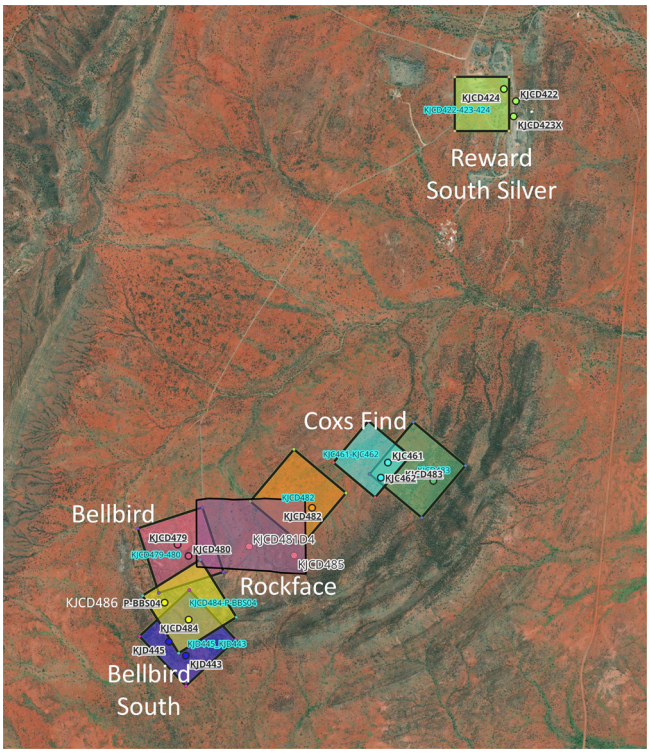

Figure 15. Relative position of transmitter loops and collars of exploration holes included in the 2021 DHEM survey at Jervois (Not to scale, North to the top of the page).

the southwest. The orientation of the DHEM conductor also correlates well with the outcropping Cox's Find deposit located 500 m to the northeast.

The narrow copper mineralisation in KJCD483, located 350 m to the east of the Cox's Find outcrop, was not directly associated with an in-hole DHEM conductor, although a small 50 m × 50 m weak off-hole conductor plate is located above the hole, ~30 m away from the copper intersection. The IP response tested by KJCD483 has been re-modelled and is now considered to be mostly the result of 'over modelling' of noisy data, which, along with the negative DHEM response, has shifted the target to a lower priority for further drilling.

Summary and conclusions

The Jervois J-fold is recognised as the large-scale host-structure of three significant copper deposits: Reward, Bellbird and Rockface, as well several smaller deposits and prospects.

The 1 km segment of the J-fold, stretching from Cox's Find prospect to Rockface, had not been explored by modern geophysical methods and, although highly prospective, had never been drilled. In 2021, this segment of the J-fold was included in an extensive MIMDAS IP program that covered 9 km of J-fold strike from Rockface to the northern boundary of the Unca Creek EL.

The prospective Rockface-Cox's Find 'gap' was the only segment of the J-fold to be covered by 'true' 3D IP. In the 'gap', the MIMDAS survey detected a moderate to strong, mostly deep-seated IP response, consistent with strike and dip projections of the known Cox's Find deposit. Drillhole KJCD482 tested the IP response to a depth of 784.2 m. The hole intersected weakly disseminated pyrite and chalcopyrite in two broad zones, with the combined length of 158 m. The implied volume of sulfide mineralisation intersected in the hole is considered to adequately explain the IP anomaly.

Within the upper zone, a 3 m interval commencing at 523 m downhole exhibited stronger disseminated chalcopyrite mineralisation. The presence of bornite was noted. Assays from the 3 m interval averaged 1.92% Cu, which is close to the overall grade of the Jervois mineral resources.

Hole KJCD482 was surveyed by 2 different DHEM probes, with the coil probe proving to be more sensitive to the low conductance style of mineralisation encountered in the hole. A large (700 m strike by 500 m dip) EM conductor was modelled, which is consistent with KJCD482 copper intersection and with a dip and strike closely corresponding to the orientation of the Cox's Find deposit. The modelled centre of the conductor plate lies to the southwest of KJCD482, a region where the IP response is also stronger.

The DHEM conductor, as modelled, extends to within tens of metres of planned Rockface underground mine openings, which has enhanced the potential economic significance of this exploration target (**Figure 7**).

The association of the observed geophysical features with the copper discovery in hole KJCD482 indicates a continuity of mineralisation that is absent in the previous Cox's find near-surface drilling. This demonstrates the power of the combination of exploration techniques employed by KGL.

The success of the geophysics-led discovery of copper mineralisation at Cox's Find South is a validation of the KGL's exploration approach.

Future program

Due to the potentially economic copper grades and thickness intersected in drillhole KJCD482 and the clear association of this copper mineralisation with a large but low conductance EM conductor, a follow-up hole is planned to further test the Cox's Find South target. The new hole will be targeted to intersect the modelled DHEM plate ~210 m southwest of the copper interval in KJCD482, and ~500 m below surface. The new hole will be surveyed by DHEM with the results to be used to refine the DHEM model and inform additional follow-up drilling.

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