Title field – Discovering Deeper Porphyry Ore Bodies – *is there a role for geophysics?*

Dan Wood
W H Bryan Mining and Geology Research Centre
University of Queensland
danwood3844@hotmail.com

SUMMARY

The anticipated almost doubling of world mine Cu production by 2030 will require a substantially increased output from existing porphyry Cu mines, along with production from as yet undeveloped mines and the discovery of new porphyry ore bodies. Assisting the potential for increased output from existing and new mines, and partly in response to declining ore grade, mass (large-scale) mining of porphyry Cu ore bodies is undergoing a major transformation, foreshadowing a significant increase in the size of some existing and future mining operations.

The discovery histories of two of the four Cadia, porphyry Au-Cu ore bodies in New South Wales, Australia offer insights into discovering deeper porphyry ore bodies. Induced polarisation geophysics (IP) contributed importantly to one of these discoveries (Ridgeway) by identifying the overlying 'sulphur' halo to the ore body.

It is proposed that IP, and possibly other geophysical methods, can play a greater role in discovering deeply-located porphyry ore bodies, when used as part of an 'ore-system' approach to discovery; particularly if the methods can be modified so as to 'see' much deeper than at present and used to identify a porphyry 'sulphur' halo, starting at a depth below surface of up to 1,000 m.

Key words: porphyry, copper, Cadia, geophysics, IP.

INTRODUCTION

World mine Cu production is expected to almost double by 2030 and since much of present production is from mining porphyry Cu ore bodies it is certain that new porphyry discoveries will need to be made and brought into production before 2030, to supply the shortfall between refined Cu metal demand and the increased production that can be extracted from existing mines.

Discoveries will need to be made in known porphyry Cu districts and in terrains which hitherto haven't produced a porphyry discovery. Unfortunately for mineral explorers, the increasing discovery maturity of many known districts suggests that new ore bodies in these will be more deeply located (as may apply in new districts as well) and the challenge will be to facilitate these deeper discoveries.

The mining industry has anticipated this move to deeper mining and mass (large-scale) open pit mining to >1,500 m depth (Ultra-deep pits), or mass underground mining to >2,000 m (Super-caves), are now accepted as methods for extending the mining life of some existing porphyry Cu ore bodies, and for developing new mines on deep, low-grade porphyry Cu mineralisation.

The porphyry Au-Cu ore bodies at Cadia, New South Wales, Australia illustrate the opportunity that may exist for both shallow and deeper discoveries in an old mining district, and their histories of discovery provide examples of one way in which this potential can be realised using geological, geochemical and geophysical methods.

Induced Polarisation geophysics (IP) played an important role in one (Ridgeway) of the Cadia discoveries where the top of the ore body is 500 m deep and all near-surface evidence of the ore is masked by up to 80 m of post-mineral basalt cover. At Ridgeway it seems probable that IP chargeability identified the ore body's 'sulphur' halo, largely in the form of disseminated pyrite, but didn't detect the deeper Cu-sulphide ore (Close, 2000).

There is nothing new in using IP to detect the pyritic halo to a porphyry Cu deposit since this was an early application of the method. The Ridgeway discovery quite effectively highlights its usefulness as an indirect porphyry ore body discovery tool, particularly where the pyritic halo starts near-surface and when used in conjunction with ore body knowledge and geological intuition. The challenge with exploring for deeper porphyry ore bodies using IP in this way is to modify the method so that it can be used to accurately detect a 'sulphur' halo that starts at a depth of up to 1,000 m below the surface.

PORPHYRY ORE BODIES

Porphyry ore bodies are economic mineral deposits where Cu, Mo or Au is the principal ore metal, usually with one of the other two metals as a lesser component of the ore. Porphyries are the major source of world Cu and Mo mine production, and an increasingly important source of Au, accounting for about 70% of the world's inventory of Cu (Sillitoe, 2012). The ore bodies are characterised by a low average ore grade and large size; requiring mass open pit or underground mining to be economic.

The term 'porphyry' was early applied to bulk low grade Cu mineralisation irrespective of the host rock and was used as a mining term (McKinstry, 1948) – an igneous porphyry, spatially associated with the mineralisation was not a requirement. The concept of mining low-grade, porphyry Cu-sulphide mineralisation is credited not to a geologist or mining engineer but to a metallurgist, Daniel C. Jackling, who first applied large-scale mining and ore processing at the Bingham Canyon Cu mine in Utah, USA in 1906 (Sutulov, 1975).

Copper Production

In 1800, world Cu mine production was 0.018 Mt and by 2010 had reached 16 Mt, and was contributing almost 83% of the world's annual usage of refined Cu metal. Since 1900, world demand for refined Cu has increased by an average of 3% per year. If a similar rate of annual increase and mine contribution are maintained for the next two decades, world refined Cu demand in 2030 will be at least 32 Mt, with a required mine Cu production of at least 26 Mt.

Mining Revolution

An operating revolution occurred in mining and processing Cu-sulphide ore in 1906 when the 200 – 300 tpd output of a typical Cu-sulphide milling and processing plant (Sutulov, 1975) was initially transformed into 2,000 tpd at the Bingham Canyon mine, quickly expanding to 6,000 tpd once the success of Jackling's mining/processing approach was proved. This enabled the average grade of Cu-sulphide ore to be halved, to 2.0% Cu.
By today's ore processing standard, 6,000 tpd is small, but the power of Jackling's innovation was that it had effected a 20- to 30-fold change of scale. An equivalent scale-increase today would lift a 250,000 tpd ore-processing operation (e.g. Escondida sulphide ore) to one that is milling and treating 5.0 – 7.5 Mtpd of Cu-sulphide ore (i.e. 1.8 – 2.7 Btpy). This isn't expected to occur in the short-medium term, but it is likely because of increasing Cu demand that several already large Cu mines will become very much larger over the next 20 years, and there will be porphyry operations mining and processing at least 1.0 Mtpd of Cu-sulphide ore by 2030.
The reason why it is reasonable to predict operations of this scale rests with anticipated future Cu demand. Unless there is major growth in the output of the Cu-recycling industry, the anticipated increase in refined Cu demand by 2030 requires almost a doubling of mine production. This can be achieved either by doubling the number of mines, or by a combination of more mines plus a significant increase in size of many existing mining operations.

Mass Mining Trend

The mining of porphyry ore bodies is presently undergoing a major scale transformation (Chitombo, 2011). Ultra-deep open pits that will be mined to a depth of at least 1,500 m are now being planned for development from existing open pit mines. Super-cave underground mines are expected to be developed that will have the ore extraction level located at a depth below surface of down to 2,000 m; and probably of 3,000 m as mass underground mining technology improves.
Accompanying these major extensions of mass mining depth are massive increases in mining scale, with material movements increasing several-fold in open pits and by up to an order of magnitude underground.

Copper Supply

Presently, about 60% of annual Cu production is from relatively small mines. In 2010, for example, the ten largest open pit and ten largest underground mines produced a combined 6.7 Mt of Cu, out of a total mine Cu production of 16.0 Mt; with the open pit mines producing twice the amount of Cu as the underground mines (MEG, 2011).
The ranges in annual Cu production of the ten largest open pit and underground Cu mines in 2010 were 0.24 – 1.0 Mt and 0.08 – 0.42 Mt, respectively. The upper and lower levels of these production ranges will need to increase significantly if the 2030 demand for refined Cu is to be met largely from mine production, as will be necessary.

CADIA DISCOVERIES

The Cadia porphyry Au-Cu ore bodies (Figure 1) in NSW, comprising Cadia Hill, Ridgeway, Cadia Quarry and Cadia East/Far East, are part of an estimated mineral resource of >44 M oz Au and 7.5 Mt Cu (Wood, 2012a & b). The first of the ore bodies to be discovered, Cadia Hill, cropped out and was located using geological intuition, combined with conventional geological and geochemical techniques, to identify the drilling target (Wood and Holliday, 1995).

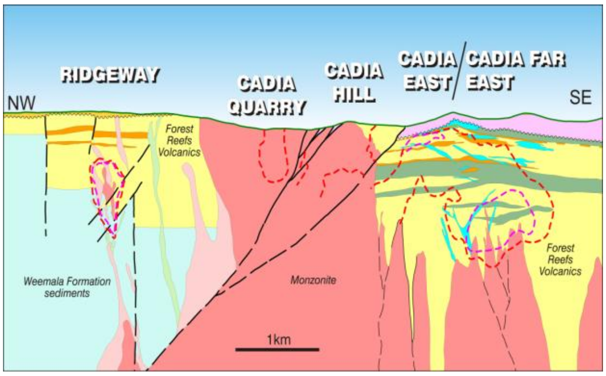

Figure 1. Schematic long-section through the Cadia porphyry Au-Cu deposits, NSW.

The shallower north-western part of the Cadia East/Far East ore body was discovered by drilling through up to 200 m of post-mineral sedimentary cover, along trend of the Cadia Hill mineralisation, immediately to the south-east of the Cadia Hill ore body (Wood and Holliday, 1995). The much deeper, higher-grade part of the Cadia East/Far East ore body, further to the south-east, was subsequently discovered by investigating the variation in Au and Cu values in the overlying large volume of shallower, moderate-grade Au-Cu mineralisation (Tedder et al., 2001).
An extensive corridor of low-grade Au-Cu mineralisation and porphyry-style hydrothermal alteration was defined by geological mapping and sampling to the NW of the Cadia Hill ore body, and a small Au-Cu mineral resource was discovered and partly mined at Cadia Quarry (Wilson et al., 2003); but exploration further to the NW of Cadia Quarry was eventually hampered by the presence of an un-mineralised intrusion and Tertiary basalt cover.
To identify discovery drilling targets in the area to the NW of Cadia Quarry, including the area under basalt cover, a reconnaissance induced polarisation (IP) geophysical survey was conducted at Cadia. Confirmation of the usefulness of IP as a targeting technique at Cadia was obtained by conducting 200m dipole-dipole IP traverses across the outcropping Cadia Hill ore body and the covered Cadia East mineralisation.
A 200 m dipole-dipole configuration was used for the IP traverses so as to provide a broad lateral coverage (about 1.5 km) and adequate depth penetration of the known

mineralisation, given the primary target of exploration at Cadia was an ore body that could be mined by open pit.

Results from the trial IP traverses clearly identified an apparent chargeability anomaly over the Cadia Hill mineralisation, and indicated that the sulphide minerals contained within the Cadia East deposit were detectable beneath up to 200 m of un-mineralised calcareous siltstone. The apparent chargeability response over the Cadia East mineralisation was 2 – 3 times background, with readings in the 10 – 13 ms range (Figure 2).

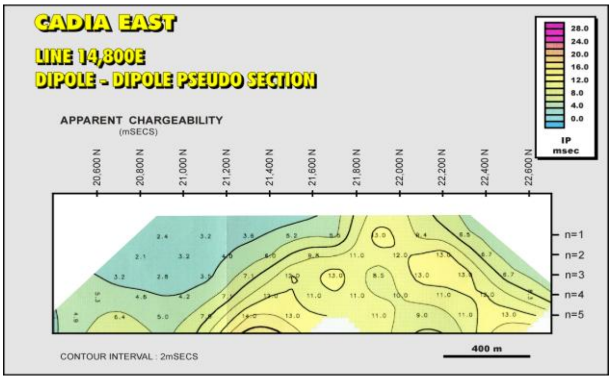

Figure 2. Dipole-dipole pseudo-section through the Cadia East mineralisation on Line 14,800 E.

From the Cadia East result it was expected that the IP response from a thickly-covered, or much deeper, porphyry ore body would only be evident in the deeper chargeability values on the IP pseudo-section. In the subsequent reconnaissance IP survey only one chargeability anomaly was detected with characteristics that could not be explained by rock type contrasts. The chargeability anomaly was detected on three 200 m-spaced traverses over the basalt-covered area.

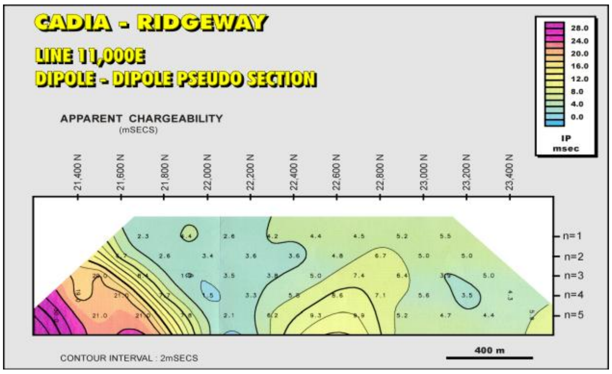

Figure 3. Dipole-dipole pseudo-section interpreted to detect the sulphide halo to the Ridgeway ore body, located 500 m below surface under 22,600 N.

This IP anomaly was investigated with nine 200 m deep, inclined reverse circulation (RC) percussion holes drilled on two traverses of drill holes spaced 400 m apart. The holes were sited 200 m apart and orientated NE. Figure 3 shows the chargeability response directly overlying the Ridgeway ore body at 22,600 N.

The Ridgeway ore body is located almost 3.0 km NW of Cadia Hill and is the highest grade of the three significant porphyry ore bodies at Cadia. It is too deeply located to be mined by open pit, but is of sufficient grade to be mined by underground caving (Figure 4).

PORPHYRY ORE BODY DISCOVERY

In the 1970 Jackling Award Lecture (Lowell, 1970), porphyry Cu ore bodies are described as "low-grade, roughly equidimensional, disseminated deposits which contain chalcopyrite, pyrite, and at least trace amounts of molybdenite, silver and gold, and which sometimes contain chalcocite and bornite."

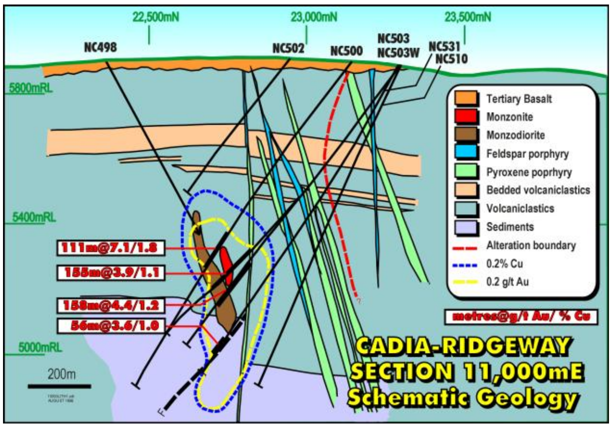

Figure 4. Schematic of Ridgeway ore body on section 11,000 E.

The general characteristics of a porphyry Cu deposit in the south-western USA were summarised in 1970, in what has become known as the Lowell and Guilbert model (Lowell and Guilbert, 1970), as an oval pipe-shaped deposit with plan dimensions of roughly 1.0 x 2.0 km, and a vertical dimension of about 3.0 km. An average porphyry Cu deposit in south-western USA in 1970 contained about 140 Mt of ore, which is small when compared with porphyry Cu ore bodies being mined today.

The most important guide to discovering porphyry deposits was considered to be the hydrothermal alteration zoning spatially associated with a deposit, which typically progresses outward from an (early) potassic core, through pyritic-phyllic, argillic, and propylitic alteration zones. Ore-grade Cu mineralisation is restricted to parts of the potassic and phyllic alteration zones.

By the late-1970s and subsequently, detailed studies of porphyry Cu deposits in other geological settings established several variations from the Lowell and Guilbert model (Sheppard et al., 1971; Taylor, 1974; Gustafson and Hunt, 1975; Sutherland-Brown, 1976; Gustafson and Titley, 1978; Titley, 1982; Lang et al., 1995; Schroeter, 1995). Other investigations at that time and subsequently have focused on understanding the genesis of porphyry deposits (Henley and McNabb, 1978; Burnham, 1979; Candela, 1991: Dilies and Einaudi, 1992).

'Ore-system' Exploration

In theory, an ore body should be easier to discover if it presents as a larger target, and this usually can be achieved relatively easily by taking an 'ore-system' approach (Wood, 2010) to the discovery task; this significantly expands the size of the target and enables a more efficient application of exploration funds. It also ensures that the exploration team has a better understanding of the dimensions of the discovery target and is better able to gauge the significance of exploration results – particularly results from drilling.

An 'ore-system' approach to discovery relies on using an ore deposit model, but one that is general rather than detailed in its description. It requires the component parts of the deposit model to be simplified so that they can be visualised as a three-dimensional dartboard, appropriately modified to accommodate the 3-D spatial characteristics of the deposit-type being sought.

Simplicity is the key to using this approach, with the target ore deposit reduced to four component parts, or rings on the dartboard – ore, mineralised waste, altered waste, and unaltered host rock. The objective in using this method is to effectively focus discovery drilling by using the results from widely-spaced reconnaissance drill holes to vector towards potential ore.

A Porphyry 'Ore-system' Example

In a south-western USA porphyry 'ore-system', for example, the outwardly progressing rings of the 3-D dartboard comprise an ore bull's-eye straddling the potassic/inner-phyllic alteration zones, a mineralised waste ring accommodating the remainder of the phyllic zone, and an altered waste ring of argillic and propylitic alteration-mineral assemblage zones, superimposed on unaltered and barren host rocks.

However, with a porphyry 'ore-system' the 3-D dartboard can be expanded beyond the immediate porphyry-related hydrothermal alteration system and can include peripheral associated mineralisation, such as mineralised skarn, as occurred with the Cadia Hill ore body discovery (Wood and Holliday, 1995). Additionally with porphyry mineralisation, the propensity for developing clustered alteration-mineralisation centres within a porphyry district offers the potential for multiple ore body discoveries.

DEEPER PORPHYRY DISCOVERY

Discovery of deeper porphyry mineralisation is occurring, but commonly as a result of geologically/geochemically-informed risk-taking. A recent example is the discovery of the La Americana and Cerro Negro Cu-Mo deposits at Andina Mine, in the Rio Blanco-Los Bronces District of Central Chile (Rivera et al., 2012).

Recent Andina Discoveries

The Cu ores presently being mined at Andina are magmatic-hydrothermal breccias and not classic porphyry Cu deposits (Rivera et al., 2012), as described by the various porphyry models. Magmatic-hydrothermal breccias, however, are a feature of many porphyry districts where they may form an ore body in their own right (e.g. the Ridgeway ore body at Cadia is a type of breccia deposit) and are a useful component of an 'ore-system' approach to exploring for a porphyry deposit.

At Andina, there is minimal, readily-attributable surface evidence of the presence of either the La Americana or Cerro Negro porphyry deposit. Tenuous possible evidence of their presence is restricted to "outcropping propylitic alteration encompassing volcanic rocks, minor breccia bodies, narrow dacite porphyry dykes, and type D veins with sericite selvages" (Rivera, et al., 2012).

Using an 'ore-system' approach to discovery, this surface evidence of possibly porphyry-related hydrothermal alteration would be relegated to the altered waste ring of the 3-D dartboard. Unfortunately, propylitic alteration is relatively commonplace and deep drilling of propylitically-altered rocks without additional evidence suggestive of porphyry discovery potential has a good chance of leading to gambler's ruin.

Fortunately at Andina, this meagre surface evidence, along with the results from previous drilling, was creatively re-interpreted as a possible outer halo to a blind porphyry deposit and followed up with deeper drilling.

In the case of the La Americana discovery, the deposit comprises a core of chalcopyrite-bornite mineralisation, mantled laterally and above by chalcopyrite, and pyrite, shells. At Cerro Negro, the porphyry mineralisation starts some 800 m below the surface, and is overlain by pyrite-rich propylitic alteration.

A ROLE FOR GEOPHYSICS

Presently, the discovery of deeper porphyry mineralisation depends to a large extent on the experience of exploration geoscientists and on their appetite for taking risk, conditioned by the risk culture within the mining company that employs them and provides the exploration budget. This situation is evidenced in reviews of porphyry deposits discovered since 1970 (Sillitoe, 1995; Sillitoe, 2000; Sillitoe and Thompson, 2006; Holliday and Cooke, 2007), which indicate that geology, geochemistry and drilling were the primary methods most attributed to discovery.

There has always been a role for geophysics in the discovery of porphyry deposits, particularly those that are more deeply located or masked by post-mineral cover. Why is it then that geophysics only ever seems to have a supporting role, at best, in porphyry discovery; unlike with volcanogenic massive sulphide deposits, where it is commonly the primary discovery method?

The deep discoveries of the Ridgeway ore body at Cadia in 1996 (Holliday et al., 1999), and of the Hugo Dummett ore body at Oyu Tolgoi in 2002 (Kirwin et al., 2003), are clear examples of how one geophysical method, IP, can be used to focus discovery drilling into an area in the search for a deeper porphyry deposit.

'Ore-system' Geophysics Required

It is suggested that geophysics will play an important role in the discovery of deeper porphyry deposits when it is able to be used with confidence to discriminate between volumetrically-large bodies of propylitic hydrothermal alteration. The potential for doing this already exists with IP (possibly used in conjunction with magneto-telluric resistivity) when the results from deeply-probing IP geophysics conducted over propylitic alteration are interpreted as part of a porphyry 'ore-system', in the search for shallowly-covered porphyry deposits.

Propylitic alteration mineral assemblages close to a porphyry deposit invariably contain disseminated pyrite and pyrite-rich veins. Research into the trace element chemistry of propylitic silicate-alteration minerals has shown that epidote may be useful in identifying the El Tenniente porphyry Cu-Mo mineralisation, at distances from the deposit where there is no evidence of mineralisation evident in conventional rock chip analyses (Baker, et al., 2012).

Using IP geophysics, for example, with this mineral chemistry is one obvious way in which geophysics, geology and geochemistry can be combined in an 'ore-system' approach to discriminating between potentially ore-bearing and barren, propylitic hydrothermal alteration. This is but one example of how geophysics may be used in the search for deeper porphyry ore bodies. Consideration of the broad geological and mineralogical characteristics of a porphyry deposit in the context of an 'ore-system' will undoubtedly identify other opportunities.

Given that the hydrothermal alteration footprint of a porphyry deposit may extend laterally and vertically for many kilometres, geophysical methods that are able to penetrate up to 1,000 m, or more, of barren hydrothermal alteration and identify the presence of disseminated and vein-controlled sulphide mineralisation clearly have an important role in the search for deeper porphyry ore bodies.

CONCLUSIONS

It is proposed that there is an important role for geophysics in the discovery of deeper porphyry ore bodies, as part of an 'ore-system' approach to discovery. IP is considered the most obvious method to assist with the discovering these ore bodies; but, with very deep discoveries, it will only achieve its potential if the depth penetration of existing IP technology is improved.

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REFERENCES

Baker, M.J., Cooke, D.R., Hollings, P.N., Wilkinson, J.J. and Wilkinson, C., 2012, Epidote trace element chemistry as an exploration tool: El Teniente porphyry Cu-Mo deposit case study: SEG 2012 Conference, Integrated Exploration and Ore deposits, Society of Economic Geologists, Lima, Peru, September 23-26, 2012, Abstracts.

Burnham, C.W., 1979, Magmas and hydrothermal fluids, in: H.L. Barnes, ed., Geochemistry of Hydrothermal Ore Deposits: 2nd edition: J. Wiley and Sons, 71-136.

Candela, P.A., 1991, Physics of aqueous phase exsolution in plutonic environments: American Mineralogist, 76, 1081-1091.

Chitombo, G., 2011, Total Deposit Knowledge – Geology, Underground Mass Mining and the Future – A Mining Engineer's Perspective: Eighth International Mining Geology Conference, Queenstown, New Zealand, 22-24 August 2011, Proceedings, 11-14.

Close, D.I., 2001, A geophysical study of the Ridgeway Gold-Copper Deposit, New South Wales: B.Sc. Honours thesis, University of Tasmania.

Dillies, J.H. and Einaudi, M.T., 1992, Wall-rock alteration and hydrothermal flow paths about the Ann-Mason porphyry Cu deposit, Nevada – a 6 km vertical reconstruction: Economic Geology, 87, 1963-2001.

Gustafson, L.B. and Hunt, J.P., 1975, The porphyry copper deposit at El Savador, Chile: Economic Geology, 70, 857-912.

Gustafson, L.B. and Titley, S.R., 1978, Porphyry Copper Deposits of the Southwestern pacific islands and Australia: Economic Geology, 73, 597-599.

Henley, R.W. and McNabb, A., 1978, Magmatic vapour plumes and ground-water interaction in porphyry copper emplacement: Economic Geology, 73, 1-20.

Holliday, J., McMillan, C. and Tedder, I., 1999, Discovery of the Cadia Ridgeway gold-copper deposit: New Generation Gold Mines – case histories of discovery, Perth, Australian Mineral Foundation, 101-107.

Kirwin, D.J., Forster, C.N., and Garamjav, D., 2003, The discovery history of the Oyu Tolgoi porphyry copper-gold deposits, SouthGobi, Mongolia: NewGenGold 2003 Conference Proceedings, 130-146.

Lang, J.R., Stanley, C.R., Thompson, J.F.H. and Dunne, K.P.E., 1995, Na-K-Ca magmatic-hydrothermal alteration in alkali porphyry Cu-Au deposits, British Columbia: Mineralogical Association of Canada Shortcourse, 23, 336-339.

Lowell, J.D. and Guilbert, J.M., 1970, Lateral and vertical alteration-mineralisation zoning in porphyry ore deposits: Economic Geology, 65, 373-407.

McKinstry, H.E., 1948: Mining Geology, Prentice-Hall Inc., Englewood Cliffs, New Jersey.

MEG, 2011, Strategies for Copper Reserves Replacement: The Costs of Finding and Acquiring Copper: Metals Economics Group.

Rivera, S.L., Cuadra, P. And Wettke, E., 2012, Discovery and Geology of La Americana and Cerro Negro: new deep porphyry Cu-Mo type mineralisation at Andina Mine, Rio Blanco-Los Bronces District, Central Chile: SEG 2012 Conference, Integrated Exploration and Ore Deposits, Lima Peru, September 23-26, 2012, Abstracts.

Sillitoe, R.H., 1995, ed., Exploration and discovery of base and precious metal deposits in the circum-Pacific region during the last 25 years: Resource Geology Special Issue, 19.

Sillitoe, R.H., 2000, ed., Exploration and discovery of base and precious metal deposits in the circum-Pacific region – a late 1990's update: Resource Geology Special Issue, 21.

Sillitoe, R.H., and Thompson, J.F.H., 2006, Changes in mineral exploration practice: consequences for discovery: Society of Economic Geologists Special Publication, 12, 193-219.

Sillitoe, R.H., 2012, Porphyry Copper Provinces: SEG 2012 Conference, Integrated Exploration and Ore Deposits, Society of Economic Geologists, Lima, Peru, September 23-26, 2012, Abstracts.

Schroeter, T.G., ed., 1995, Porphyry deposits of the Northwestern Cordillera of North America: Canadian Institute of Mining and Metallurgy Special Volume, 46.

Sheppard, S.M.F., Neilsen, R.L. and Taylor Jr, H.P., 1971, Hydrogen and oxygen isotope ratios in minerals from porphyry copper deposits: Economic Geology, 66, 515-542.

Sutherland-Brown, A., 1976, ed., Porphyry deposits of the Canadian Cordillera: Canadian Institute of Mining and Metallurgy Special Volume, 15, 510 p.

Sutulov, A., 1975, Copper Porphyries: Miller Freeman Publications, Inc.

Taylor, H.P., Jr., 1974, The application of oxygen and hydrogen isotope studies to problems of hydrothermal alteration and ore deposition: Economic Geology, 69, 843-883.

Tedder, I.J., Holliday, J. and Hayward, S., 2001, Discovery and evaluation drilling of the Cadia Far East gold-copper deposit: NewGen Gold 2001 – Case Histories of Discovery, Australian Mineral Foundation, 171-184.

Titley, S.R., 1982, ed., Advances in geology of the porphyry copper deposits Southwestern North America: University of Arizona Press, Tucson, Arizona.

Wilson, A.J., Cooke, D.R. and Harper, B.L., 2003, The Ridgeway gold-copper deposit: a high-grade alkali porphyry deposit in the Lachlan Fold Belt, NSW, Australia: Economic Geology, 98, 1637-1666.

Wood, D., 2010, Mineral resource Discovery – Science, Art & Business: SEG Newsletter, January 2010, 12-17.

Wood, D., 2012a, Discovery of the Cadia Deposits, NSW, Australia (Part 1): SEG Newsletter, January 2012, 1, 13-18.

Wood, D., 2012b, Discovery of the Cadia Deposits, NSW, Australia (Part 2): SEG Newsletter, April 2012, 1, 17-22.

Wood, D. G. and Holliday, J.R., 1995, Discovery of the Cadia gold-copper deposit in New South Wales by refocusing the results of previous work: New Generation Gold Mines Case Histories of Discoveries Conference Proceedings, Australian Mineral Foundation, South Australia.