Copper porphyry districts - Chile & Associates

When people talk about copper porphyry deposits, I am always thinking about South America. There are some in the Philippines and Indonesia but not in the same frequency. Over the years, I have not paid too much attention to the details that surround these deposits as it seems too complicated. I have been curious, but it seems to be not straightforward, and each deposit is different. However, I have noticed some of the recent discoveries coming out of the area, and that has sparked some of my interest. The more I got into it, the more I was fascinated with the story.

One of the fascinating points of these deposits is the concentration in Chile. The deposits seem to be constrained to one time period and deposits cluster together with similar metal contents and styles of mineralisation.
Figure 1: Locations of significant Chilean porphyry deposits in Northern Chile (source: www.kuraminerals.com).

A good way to understand these deposits (according to theory) is to look at the mechanism of a subduction zone. What is a subduction zone you may ask?

A Subduction Zone
I am going to give a chinaman explanation. For those that want more details, Mr Google has plenty of examples. The world consists of a series of tectonic plates that move around and slide into and over each other at the boundaries. The diagram below, Figure 2, outlines where these subduction zones are located within the Pacific Plates.

Figure 2: Subduction zones (source: www.livescience.com).

When these plates collide and the process of 'subduction' happens (Figure 3), a lot of things happen and one is the...
creation of 'Back-Arc'. This is what caused the potential formation of these metallogenic belts that are shown in Figure 1.

A schematic cross-section representation of the process subduction is shown in Figure 3. The metallogenic 'belts' are the creation of the Arc, as shown in Figure 3.

![Figure 3: A schematic representation of a subduction zone (source: www.kuraminerals.com).](image)

As the subduction process is ongoing over geological time, the different belts are created over time. It is interesting that the different events appear to bring up different metal content within the deposits.

If you look closely in Figure 1, there appears to be a spatial separation of deposit types, IOCG, Manto-type Cu Ag, Porphyry Cu and Epithermal Au and Cu. There seems to be something controlling where the types of deposits are found but what is pretty obvious is the rich source that is feeding this part of the world.

Fortunately, this article cannot explain all the facts so I will leave that to those who actually know what they are talking about. As they say, when you have enough to be dangerous, one can create all sorts of issues.

What is so special about these Chilean deposits
According to Camus, F and Dilles J.H 2001 [5], Chile is known to have the largest concentration of copper on Earth. At that time (24 in production), exploration expenditure in the region had exceeded US$2 billion, with 76 copper and gold discoveries.
Due to the amount of work that has been done over the years, Chile has become the premier place to come and find that big mother lode. Expensive it may be for exploration, but the prize of discovery is enormous.

There is a good summary I found on the www.kuraminerals.com site.

“The world’s largest and richest porphyry Cu-Mo deposits occur in the northern portions of the Chilean Andes and have allowed Chile to become not only the leading copper-producing country (5,764 kMT of copper were produced in 2015, 30% of annual global copper production) but also the second largest producer of molybdenum (52,579 MT in 2015) as a by-product of the copper exploitation.

“Despite the fact that Chile’s overall mineral wealth lies mainly in these world class Cu-Mo porphyry deposits, it is important to acknowledge other significant metallic ore occurrences, such as epithermal Au-Ag, iron oxide-copper-gold (IOCG), volcanic-hosted manto-type Cu-Ag, iron ore-apatite, mesothermal Cu-Au-Ag- vein and minor skarns Cu-Ag-Au deposits.”

According to an article I found (Cooke DR, Hollings P, Walshe JL (2005) Giant porphyry deposits-characteristics, distribution and tectonic controls. Economic Geology, v. 100) [2], more than half of the 25 largest known porphyry copper deposits, defined in terms of contained copper metal, formed during three time periods: the Paleocene to Eocene, Eocene to Oligocene, and middle Miocene to Pliocene. Something that is consistent with what has been shown in Figure 1, for Chilean projects.

These giant deposits are clustered within three provinces, central Chile, northern Chile, and southwest Arizona-northern Mexico. The other giant deposits occur in Montana, Utah, Panama, Peru, Argentina, Irian Jaya, Mongolia and Iran.

Compressive tectonic environments thickened continental crust, and active uplift and erosion were associated with the formation of many of these deposits. Calc-alkalic magmas are most favourable for the formation of giant porphyry copper deposits, although several of the largest systems are associated with high K calc-alkalic intrusions.
In addition, the 25 largest of these deposits are found in the southwest Pacific and South America. The dominance of Chile as a giant copper porphyry mecca can be seen in Table 1 which was taken from a paper published in 2005 [2]. Similarly, there is a lack of gold-related projects in Chile (Table 2). This is not to say that there are none, it’s just not a “giant” status.

I am not sure what the statistics are like now. It is 15 years since 2005 but without researching that fact, I can’t see the percentage dominance changing much, in terms of Chile having a higher frequency of giant copper deposits.

To discover one of these giants is difficult and proving the deposit up is even harder. Since the downturn of the industry in 1999, I have not seen a large rise in exploration funding for any commodity in scale.

However, what we are seeing is the gradual decrease in metal stockpiles which is starting to create some funding towards real exploration. As much as I like to think this will be increasing, my heart does tell me that it will still be a slow wait. There is a sentiment of positivity and in some way, the slow and steady growth is a good thing. It will last longer.

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Table 1: The twenty-Five Largest Known Porphyry Copper Deposits, Based in Contained Copper Metal. (source: Cooke, Holdings and Walshe, 2005 [2])

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The largest of the deposits are associated with high K calc-alkalic intrusions. Many calc-alkalic porphyritic intrusions have also produced giant gold-rich porphyries.

In the last 20 m.y., the formation of giant porphyry copper-molybdenum and copper-gold deposits in the circum-Pacific region has been closely associated with subduction of aseismic ridges, seamount chains, and oceanic plateaus beneath the oceanic island and continental arcs.

In several examples, these tectonic perturbations have promoted flat-slab subduction, crustal thickening, uplift and erosion, and adakitic magmatism coeval with the formation of well-endowed porphyry and/or epithermal mineral provinces.

Similar tectonic features are inferred to be associated with the giant porphyry copper-molybdenum provinces of northern Chile (Eocene-Oligocene) and southwest United States (Cretaceous-Paleocene).

Chile’s Metallogenic Belts
As I have mentioned previously, the Chilean mineralisation appears to be related to six geological age range (see Figure 1), which is listed below:

- Late Palaeozoic - Triassic (298-230 Ma)
- Early Cretaceous (132-97 Ma)

Table 2: The Twenty-Five Largest Known Gold-Rich Porphyry Copper Deposits, Ranked on Contained Gold. (source: Cooke, Holdings and Walshe, 2005) [2]

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Province</th>
<th>Age (Ma)</th>
<th>Tonnage (Mt)</th>
<th>Au (g/t)</th>
<th>Au (t)</th>
<th>Cu (wt %)</th>
<th>Cu (Mt)</th>
<th>Mo (wt %)</th>
<th>Mo (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasberg</td>
<td>Irian Jaya</td>
<td>3</td>
<td>2,480</td>
<td>1.05</td>
<td>2,604</td>
<td>1.13</td>
<td>28.02</td>
<td>0.02</td>
<td>0.81</td>
</tr>
<tr>
<td>Bingham</td>
<td>Utah</td>
<td>38.8</td>
<td>3,228</td>
<td>0.50</td>
<td>1,603</td>
<td>0.88</td>
<td>28.46</td>
<td>0.02</td>
<td>1.12</td>
</tr>
<tr>
<td>Kaf’makyr</td>
<td>Uzbekistan</td>
<td>310-294</td>
<td>2,700</td>
<td>0.51</td>
<td>1,374</td>
<td>0.40</td>
<td>10.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepanto-</td>
<td>N. Luzon</td>
<td>1.5-1.2</td>
<td>685</td>
<td>1.42</td>
<td>973</td>
<td>0.80</td>
<td>5.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cerro Casale</td>
<td>Chile</td>
<td>13.5</td>
<td>1,285</td>
<td>0.70</td>
<td>900</td>
<td>0.35</td>
<td>4.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadia</td>
<td>NSW</td>
<td>440</td>
<td>1,070</td>
<td>0.77</td>
<td>823</td>
<td>0.31</td>
<td>3.38</td>
<td></td>
<td></td>
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<tr>
<td>Panguna</td>
<td>Bougainville</td>
<td>3.5</td>
<td>1,415</td>
<td>0.57</td>
<td>799</td>
<td>0.46</td>
<td>6.51</td>
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<tr>
<td>Oyu Tolgoi</td>
<td>Mongolia</td>
<td>411</td>
<td>2,467</td>
<td>0.32</td>
<td>790</td>
<td>0.83</td>
<td>20.57</td>
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<tr>
<td>Batu Hijau</td>
<td>Indonesia</td>
<td>3.7</td>
<td>1,644</td>
<td>0.35</td>
<td>572</td>
<td>0.44</td>
<td>7.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minas Conga</td>
<td>Northern Peru</td>
<td>20</td>
<td>641</td>
<td>0.79</td>
<td>506</td>
<td>0.30</td>
<td>1.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ok Tedi</td>
<td>PNG</td>
<td>1.2-1.1</td>
<td>700</td>
<td>0.64</td>
<td>446</td>
<td>0.64</td>
<td>4.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>El Teniente</td>
<td>Central Chile</td>
<td>4.8</td>
<td>11,845</td>
<td>0.035</td>
<td>437</td>
<td>0.63</td>
<td>94.35</td>
<td>0.02</td>
<td>2.50</td>
</tr>
<tr>
<td>La Escendida</td>
<td>Northern Chile</td>
<td>3.8</td>
<td>2,262</td>
<td>0.19</td>
<td>430</td>
<td>1.15</td>
<td>32.49</td>
<td>0.021</td>
<td>0.48</td>
</tr>
<tr>
<td>Peschanka</td>
<td>Kamchatka</td>
<td>L. Jur.</td>
<td>940</td>
<td>0.42</td>
<td>395</td>
<td>0.51</td>
<td>4.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dalnegay</td>
<td>Uzbekistan</td>
<td>310-294</td>
<td>545</td>
<td>0.69</td>
<td>376</td>
<td>0.59</td>
<td>3.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bajo de la Atumbrera</td>
<td>Argentina</td>
<td>8-7</td>
<td>551</td>
<td>0.67</td>
<td>369</td>
<td>0.52</td>
<td>2.87</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Palaeocene- Early Eocene (60-50 Ma)
Late Eocene-early Oligocene (43-31 Ma)
Late Miocene-early Pliocene (12-4.3Ma)

The two youngest porphyry belts are the most important from an economic viewpoint (see Figure 1). They have the largest deposits and concentrating most current mining operations. The majority of the older porphyry Cu-Mo deposits are subeconomic (in 2007). Only Cerro Colorado (Eocene), Lomas Bayas (Palaeocene), Andacollo and Dos Amigos (Early Cretaceous, are currently mined (2005) and Spence (Eocene) is under development.

Late Eocene-early Oligocene
This is the most significant Chilean porphyry belt. It extends for 1400km along the Domeyko Cordillera and can be traced from the Peruvian border. There are up to 30 Cu-Mo deposits and prospects with the highest amount of copper resources. Has 220 million tonnes of Cu.

The deposits are not regularly distributed along on this north-south trending belt, but rather form local clusters with areas of <200 km2.-1945.

Other porphyry deposits
Just to make sure readers are aware, there are other porphyry deposits. As you would expect, during the research part of this article, I came across a lot of information. I know there are many other copper porphyry deposits in the world. There is Tujuh Bukit in Indonesia, the giant Bingham Cu-Mo-Au in Utah USA and many others spread all over the world. I came across one project in China and learned that the porphyry here is different from those that are at the Andes. I am sure that there are more cases of similar type deposits but while researching, it just happened that I came across these in China before the others.

Most porphyry Cu deposits in the world occur in magmatic arc settings and are formed in association with calc-alkaline arc magmas related to subduction of oceanic-slab, including porphyry Cu-Au and gold-rich porphyry Cu deposits which usually distributed in island arc setting, while porphyry Cu-Mo, Mo deposits in continental arc settings.[4]

There are some significant porphyry Cu deposits in China, unrelated subduction, including porphyry Cu(-Mo,-Au), Mo, Au, Pb-Zn deposits, mainly distributed in Tibet, Qinling collisional orogen belts, and Yanshanian intracontinental settings in Eastern China. These porphyry deposits show many differences from those which are formed in magmatic arc settings, such as geodynamic settings, tectonic control, magma source, and ore-forming fluid system. [4]

I have chosen a Chinese example as they are normally not talked about in the general public. If these projects ever come into an Australian Stock Exchange (ASX) company, most people would not have been exposed to what is in China. It occurs within a cluster of other porphyry deposits but this area is relatively unknown to the general investor.

Similarly, most investors did not know about the clusters of nickel mines that run north of the nickel sulphide project owned by Blackstone Minerals Limited (ASX:BSX) in Vietnam.

You can watch Scott Williamson talking on Coffee with Samso about the Ta Khoa project in Vietnam.


Coffee with Samso - Episode 007 - Blackstone Minerals Limited: Not just mining Nickel.

The giant Pulang porphyry Cu-Au district (446.8 million tonnes at 0.52% Cu and 0.18 g/tonne Au) is in the southern segment of the Yidun arc (Zhongdian arc), part of the Sanjiang Tethyan orogenic belt in southwest China [1]. The district consists of three deposits: South Pulang (~96% of the total ore reserves) and the smaller East and North Pulang deposits. Four intrusive phases host the three Pulang deposits.

The sequence of intrusion emplacement, alteration and veining, and sulfide associations at the three deposits suggests
that South and North Pulang are two separate porphyry Cu-Au deposits, whereas East Pulang is probably a distal part of South Pulang[1].

Figure 4: (a) Tectonic framework of the Yidun arc (after Wang et al., 2014), and (b) sketch geological map of the Zhongdian arc (after Leng et al., 2012). Abbreviations: BNS = BangongNujiang suture, GLS = Garze-Litang suture, JS = Jinshajiang suture, LB = Lhasa block, NCC = North China craton, QTB = Qiangtang block, SGT = Songpan-Garze terrane; TTD = Tibetan Tectonic domain, YB = Yangtze block, YC = Yangtze craton, YDT = Yidun terrane, ZM = Zhongza massif. (source: Cao, Kang & Yang, Zhiming & Xu, Ji-Feng & Fu, Bin & Li, Wei-Kai & Sun, Mao-Yu. (2018). Origin of dioritic magma and its contribution to porphyry Cu-Au mineralisation at Pulang in the Yidun arc, eastern Tibet. Lithos. 304. 10.1016/j.lithos.2018.02.018.)

As you can see from Figure 4, the age of the zones and the clustering of porphyry deposits are very similar to those in Chile. If one would look at the margins of all these subduction zones, you would see similar geology, age, and
mineralisation styles.

The diagram below, a schematic cross-section of the Pulang tectonic setting, is a good way to show how these porphyry deposits are form and the setting that they are found. When you compare the parallel North-South alignments in Figure 1 with Figure 5, you can see why the Chilean projects occur in that orientation. Each event of mineralisation or each rise of the magma (Figure 5) creates the deposits.

Figure 5: Tectonic setting and metallogenic model diagram of the Pulang porphyry Cu (-Mo-Au) deposit. (source: [3])

The next event, the next mineralisation event will on another parallel alignment and the younger the deposit, the more recent event will be closer and closer to the water's edge. This is the most simplistic way I can describe the process. I hope the academics don't have a heart attack.

Why my interest in copper porphyry?

In 2009, I was introduced to a company working in Chile. That company was Hot Chili Limited (ASX:HCH). I have not really looked into this part of the mineral resource, in terms of country, geology, mineralisation styles or companies involved till now.

At that time, HCH was an interesting company which was doing gold and uranium (if I am not mistaken) that was in Chile and working in the 'porphyry world'. A good associate of mine introduced me to the company. The two share price charts give a good history of the life of the company. I won't go into details on what happened but suffice to say the last 12 months could bring the stock status higher, over time.
Several months ago, an associate sent me an HCH announcement of the first drilling phase, and I was impressed. I read the details and told him that this was a "discovery" and there is no doubt that they have a mineralised porphyry. My only concern was that this was a porphyry and it was going to take a while to sort itself out. Subsequent drill results supported the discovery comment and the rising share price (Table 1 and Table 2) indicate that the market is thinking the same.

It was at this point that I decided that I want to look at the porphyry deposits and find out what it is all about. As I have mentioned, I have looked at this style of mineralisation before, but I have never done it in any detail. I knew about the likes of Batu Hijau, Grasberg, the PNG deposits and the South American deposits.

Now that I have learned more about this topic, I am pretty impressed and keen on these deposits. I do continue to stand by the fact that exploring these styles means bigger budgets. A raise of AUD$5M on the ASX is not going to cut it unless there is a plan to support this raise with subsequent funding options.

The likes of HCH is not an overnight success story. They have been doing this since 2010, and I am sure management has been persistent. Do not underestimate the quality of management in this case. For this company to be still in this space for so long and persisted and have done the corporate deals means that there is a bit of stuff in those brains.
I have never met the management, but I think this is a pretty safe assumption. One would not be able to get their hands on these kinds of projects without being in the know about the subject space.

My point here is that if there are investors looking in this space, pay keen attention to the management. This kind of deposits is like running a marathon. Not a 100m sprint. The company you are looking at needs good people to sustain the long term play.

Figure 7: A recent share price chart of HCH. Recovery from a low of AUD$0.009 to the current price of AUD$0.036 on the back of recent drill results in Chile (source: www.commsec.com.au).

Conclusion
Over the years, from a corporate point of view, I have always stayed away from things that are not in my sphere of knowledge and things that are way too complicated. Looking at these porphyry deposits would never have been in my thoughts.

Now that I have had done a fair bit of research on this topic, I can understand why many companies go searching for this prize. Looking at the image of Escondida in the feature photo, one can see the riches that could be obtained. In a place like Chile, where the discoveries of large porphyry-style deposits are more common, the likes of Hot Chili may not
be too far from their 'holy grail'.

I have come across a lot of prospects in the ASEAN region and my conclusion is that it will take a lot of hard work in terms of attracting funding and actual geological work. Hence, investors will need to be aware if they are looking in this area.

The South American deposits are no different. However, my thoughts on these 'forbidden areas' have changed. I think that with the right investing community, these deposit styles can be obtainable. Like all exploration projects, it is all about attrition. The longer you can play the game, the more chances you have to find the prize.

Remember, North American resource companies have been playing in this region for decades. The TSX (Toronto Stock Exchange) has loads of companies that play in this region.

I think what HCH did recently in getting access to a 'de-risked' project is a good move. What I mean is the acquisition of the Cortedera project with some historical drilling success is a good move, at least corporately anyway. The deal has allowed the share price of the stock to climb from sub-AUD$ 0.01 to AUD$0.036 (Figure 7). It was definitely a good deal and the market is liking what is coming out of the company.

The drill results that are being released are definitely more than a good intercept and the length of the intercept is consistent with a porphyry-like style of mineralisation. If you have read the book on the discovery of Olympic Dam, one would appreciate the feeling of potentially finding something ‘big’.

The likes of HCH will take a while to 'develop' this project but at least one can take comfort that they have something to develop.

References:
[1] Geology and Genesis of the Giant Pulang Porphyry Cu-Au District, Yunnan, Southwest China, Kang Cao ; Zhi-Ming Yang ; John Mavrogenes ; Noel C. White ; Ji-Feng Xu ; Yang Li ; Wei-Kai Li, Economic Geology (2019) 114 (2): 275-301
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