Sedimentary Copper Deposits : Which basin is hiding the next Big Copperbelt ?

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SUMMARY

Sedimentary Copper Deposits have been significant copper producers for over a hundred years and are now more important producers than ever. Where are the new giant belts like the Central African Copper belt and the Kupferschiefer belt in Poland going to be discovered worldwide and how.

Sedimentary Copper deposits are some of the most sustainable copper developments as they are high grade, meaning they can be mined underground, involve less tailings and waste dumps. They are often found in flat lying low density population regions.

Developing copper belts worldwide such as the Kalahari Copper Belt, Africa and the Sullivan Belt in North America are outlined and analysed on how modern exploration techniques can be used to unlock these belts larger scale potential.

A number of basins worldwide are now being explored on a belt scale model of basin systems. In Australia many large ancient basins have not been fully explored due to thick cover sequences such as the McArthur River Basin, NT, Gawler Craton, SA, and the Paterson Province in WA. Advances in basin wide geological modelling for these ore systems especially utilising improved regional geophysical survey techniques is unlocking potential for new giant style deposits.

Key words: Copper, sedimentary copper, developing copper basins, exploration

INTRODUCTION

Sedimentary Copper Deposits have been significant copper producers for eight hundred years and are now more important than ever. The paper will address where are we going to find further economic deposits and how we are going to find them.

Where are the new giant belts like the Central African Copper belt and the Kupferschiefer belt in Poland going to be discovered worldwide and in Australia. Sedimentary Copper deposits are some of the most sustainable copper developments as they are high-grade meaning they can be mined underground, require less tailings and have been found in low density population regions. In contrast Porphyry Copper deposits are low grade, generally require very large open pits with enormous waste dumps and tailings dams and are found in the Pacific Ring of Fire with high relief, rainfall areas and high population densities.

Developing copper belts worldwide such as the Kalahari Copper Belt, Africa and the Sullivan Belt in North America will be outlined and the modern exploration techniques being used described with a discussion on how to unlock their potential. Worldwide and Australian Belts such as the McArthur River, Northern Territory, Gawler Craton, South Australia and the Paterson Province in West Australia are discussed on how advancing of geological understandings and new tools are being utilised regionally to explore for new giant style deposits.

Global Impact of Sedimentary Copper Deposits

Water has become one of the biggest issues facing the mining industry. Major open pit copper mines with tailings dams and waste rocks will become impossible to develop in tropical zones of high rainfall especially in areas with steep topography, are seismically active and highly populated. Porphyry Copper deposits are predominantly found in the 'Pacific Ring of Fire' which consists of young volcanic mountain chains with high rainfall and population density (Valenta et al 2019).

Sedimentary Copper deposits have high-grade copper meaning they can be mined underground, require smaller surface footprints, less tailings and have been found in low density population regions. These deposits are commonly low in sulphides and don't have the large pyrite haloes found in porphyry deposits meaning waste is not acid generating and frequently the ore is hosted in calcareus rocks meaning there is a natural acid buffering. This coupled with the higher grade clean copper concentrates produced means less polluting and more sustainable mining.

Modern high quality underground developments are feasible in sensitive areas but need new technology, stringent monitoring and excellent community engagement to be approved. The Black Butte Copper Project, Montana (https://.BlackButteCopper (2021)) demonstrates the length in community consultation and commitment to technology required to develop a project in a populated location. These developments will set the standard going forward for the industry despite initially being more expensive to develop.

Global Distribution of Sedimentary Copper Deposits in space and time

Two giant belts dominate production in Sedimentary Copper deposits worldwide, the Central African Copperbelt and the Kupfeischiefer in Poland. These two belts have produced for centuries and currently produce over 15% of the worlds copper. A number of other deposits are known but the belts have not yet become significant producers due to either the size of the mineralised systems, logistics and politics.

The understanding of Sedimentary Copper is well known with the important criteria well defined and in broad concepts including :

- Basins, rift to sag phase formed during continental plate such as Gondwana, Pangea and Rodinia break-ups
- Oxidised fluids in thick immature rift sequences
- Evaporites, magmatism and high heat flow, +/- hydrocarbons
- Basin wide oxidation boundary at base of sag phase
- Inversion tectonics leading to fluid movement onto paleo highs, basin margins and antiformal traps

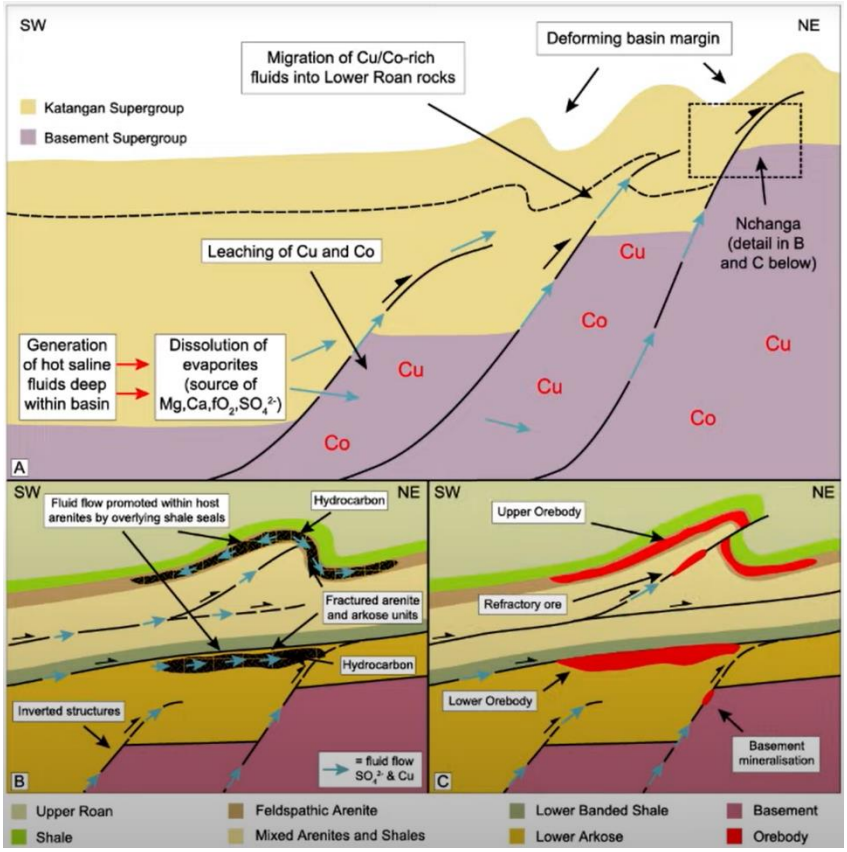

Figure 1. Model of Copper deposition in the Central African Copper Belt at Nchanga demonstrating the understanding of fluid movement out of the basin on to the basement margins during inversion (McGowan et al 2006).

Understanding the basin architecture, fluid movements in enriching copper fluids, moving fluids upwards during basin inversion and then precipitation of copper on reductants in structural traps on the basin highs is key to driving tenement acquisition and exploration targeting. A whole of basin understanding utilising regional geological and geophysical data is key to discovering more copper and defining new provinces.

The Central African Copper Belt was the site of new discoveries from the start of modern exploration with discoveries at Kafue, Zambia in 1902. Discoveries have continued for over a century, regularly increasing production from the belt. The largest discovery at Kamoa was however only recently discovered in 2014 despite the amount of exploration activity and number of discoveries during the previous century. The Kamoa deposit at 1.7 Bt @ 2.5% Cu (43 Mt Cu) lies at shallow depth on the margin of the known belt but was not discovered until the search went out onto the basin margin. The discovery history includes the normal teamwork, excellence in thinking and good fortune (Gilchrist G, 2020).

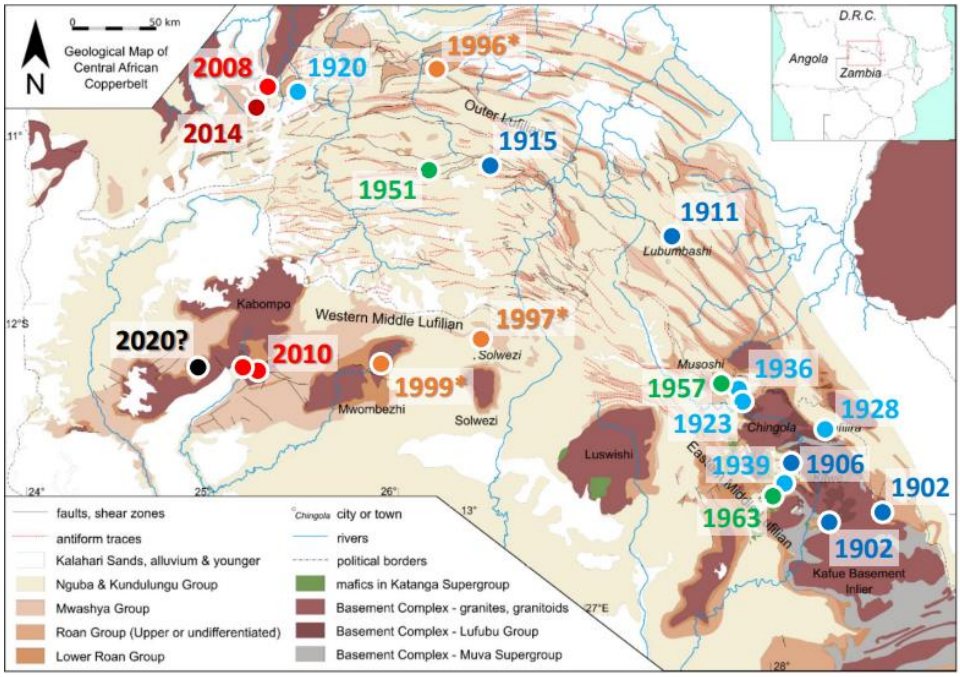

Figure 2. Location of new discoveries in the Central African Copperbelt over 120 years of modern exploration. The Kamoa deposit discovered in 2014 on the north western margins of the basin on the basement high (Wesby T., 2020).

Productive belts still have the potential to become major producers if have not been fully explored due to the flat lying nature of sedimentary deposits, very limited alteration haloes and most importantly being in covered sequences. Modern exploration, especially the improvement in airborne EM systems is assisting in defining the conductive reductants at depth and opening potential to look deeper. This is being demonstrated in the Kalahari Copperbelt which has recently become a significant copper producer.

Developing Copper Belts : Kalahari Copperbelt

Mineralisation has been mined in the Kalahri Copperbelt for over 70 years from both the western end at Rehoboth in Namibia and over 500 kilometres to the eastern end of the belt near Boseto in Botswana. Known deposits have been small and very limited production in short bursts. This has now changed dramatically with the definition of over 7 Mt of contained Copper in resources and the opening of Cupric's Zone 5 mine producing 60,000 tpa. and Sandfire Resources Motheo mine with up to 50,000 tpa of production planned (Sandfire Resources website, 2021). These deposits are under less than 30m of cover and work is now extending deeper under the sands with copper being widely intercepted on the prospective NPF_D'Kar contact. Further resources are likely to be defined over the next few years.

The potential for the belt has been hidden by the recent Kalahari Sands that vary from 0 to 120m of cover which has masked the new discoveries. Greater understanding of the geological systems, detailed aeromagnetics and high quality airborne Heli-EM has helped unlock this potential. Regional studies define the antiforms, major shear zones and mapping from aeromagnetics gives the reductant targets on the prospective contact. Exploration is now aggressively testing these models, targets being tested onto the paleo-highs in structural traps.

Key to targeting is the understanding of the basin development, key magmatic centres, the prospective first reductant on the NPF-D'Kar contact and most importantly the basin inversion. Copper rich fluids have been expelled during

basin burial and inversion and mobilised on major structures onto the basin margins and paleo-highs. Copper deposition is being discovered on major shear zones at the prospective contact like Zone 5 and Ngami and in the overlying sequence in antiformal trap sites such as Motheo.

The high-quality aeromagnetic data can define the contact of the non-magnetic NPF Formation with the more magnetic D'Kar Formation. This contact is then mapped under Kalahari sand cover in a thrusted ramp-fold pattern with a south-eastern closure direction with associated back thrusts. Targets are defined on the basin margins, on domes and major shear zones as prospective for major copper deposits. Where the cover is not too conductive then Heli-EM allows mapping of the black shale conductors and can map prospective zones of lower conductivity where altered and mineralising fluids are deposited, frequently at fault tip zones in antiformal closures.

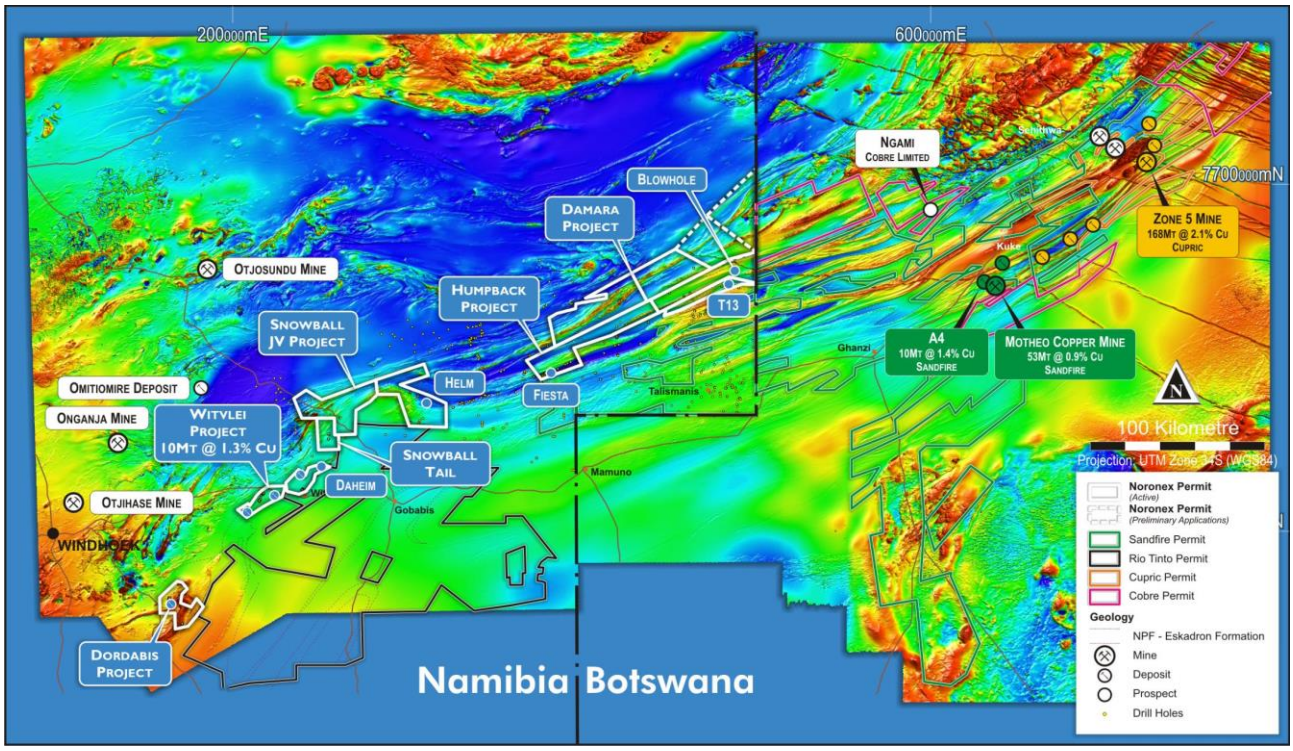

Figure 3. Aeromagnetic image of the Kalahari Copperbelt demonstrating developing exploration targets under sand cover using structural modelling of fluid flow into basin margin deformational antiforms (Noronex website, 2022)

Developing Copperbelts : Sullivan Belt

Exploration in the Sullivan Belt crossing between Canada and the USA demonstrates the variety of deposits within a mineralised belt. The Sullivan deposit in Canada has been well defined but the majority of the belt lies within the USA. Regional geophysical understanding of the basin architecture is required to explore the covered areas. No pre-competitive government data acquisition, little ability for companies to fly large regional aeromagnetic/airborne EM systems due to private mineral rights which hampers any near term opportunity to understand the belt.

Within the USA the mining tenement system is therefore sterilising any potential for discovery due to a lack of regional understanding. The licensing system has not changed in 200 years with no digital applications and small claim block size,s even on federal land, discouraging exploration companies. This is coupled with no recording of previous exploration and American geologists predominantly being archaic in their geological understanding and in new technology. The belt contains excellent potential for further discoveries as identified at the Black Butte Copper Project, Montana (https://.BlackButteCopper (2021)) but any modern exploration is hampered by these poor practices and the low chance of permitting any potential discovery discouraging investment.

Potential New Worldwide Copperbelts

A number of mines with many similarities to the major giant deposits are known and these belts have potential to become major producing belts. A number of these belts worldwide have been well explored but a number of others are poorly understood or very remote, potential remains high in a number of districts including :

In North America, the Nunavut, Canada district at Allen Bay is above the Arctic Circle close to the Northwest Passage and logistically very expensive to explore. Mineralisation was discovered in the 1960's bur due to the location active drilling only recently has confirmed the thick, high grade mineralisation in stratiform layers. Mineralisation is associated with regional conductive horizons and the basin has the potential to be a major copper producer (Aston Bay Holdings website, 2022). Regional studies are helping understand the potential in this incredibly remote region.

The Redstone district in the Northwest Territories is also isolated but has good exposure with extensive narrow copper horizons developed. A basin approach to find the trap zones where structural and basement margin targets is required to generate significant copper accumulations (Milton J, 2020).

Newfoundland has a number of small deposits with classic basin development but so far no evidence for large economic systems. Further regional pre-competitive data is required to encourage exploration in the belt.

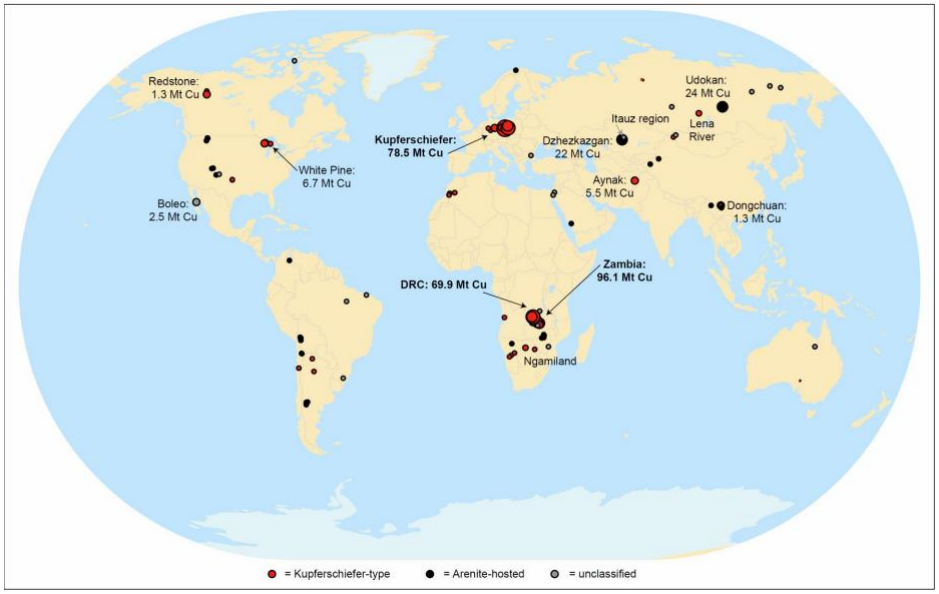

Figure 4. Worldwide location of Sedimentary Copper deposits and potential further belts (Milton J, 2020).

In Africa, Morocco has potential to be a significant new producing belt with a failed Permian rift system, a Cretaceous age inversion event with copper hosted in a reduced basal conglomerate on the rift shoulder. Understanding of the basin system is demonstrating potential for new discoveries with regional studies needed to assist in project generation. The arid, low population density region is a good location for mine development which is encouraged by the government (Reynolds N, pers comm).

The Udokan deposit, Baikal, Russia is the largest copper (26Mt Cu) deposit in Russia and is being developed as a major producer, the scale of the deposit makes this belt important globally. The deposit is in a mountainous and sensitive area which has been explored on surface with potential likely to be in further flat lying deposits that may not outcrop.

The Chu-Sarysu basin of Central Kazakhstan (Zheezkazgan 22 Mt Cu) hosted in red bed sandstones sequence deposited in broad anticlines with relic hydrocarbons during Upper Carboniferous time. A number of other copper mines have been developed in the region and due to good outcrop has been well explored. The area has a low population density and supportive for development of new copper mines.

Large sedimentary copper deposits have significant size footprints and need to be targeted with an understanding of their lateral and stratigraphic controls. Despite these deposits not having alteration haloes they can be found at depth with broad spaced drill patterns.

Australian Sedimentary Basins

Australia contains a number of sedimentary hosted Copper deposits including the historic Mt Isa district which contains some similarities to the theme. There are however a number of basins with a close analogues to the central African Copperbelt.

The CSIRO have worked on a lithosphere thickness model which demonstrates a number of potential covered basins to explore (Hoggard et al, 2020). Increased understanding of these basins, the formation of sediment hosted copper deposits and the use of airborne geophysical data is driving exploration to discover new deposits. Correlations with Africa and the known Copper deposits demonstrate a strong relationship with a 170 km deep mantle line on craton margins. These basins are frequently covered by deep recent sediments that will continue to hinder exploration.

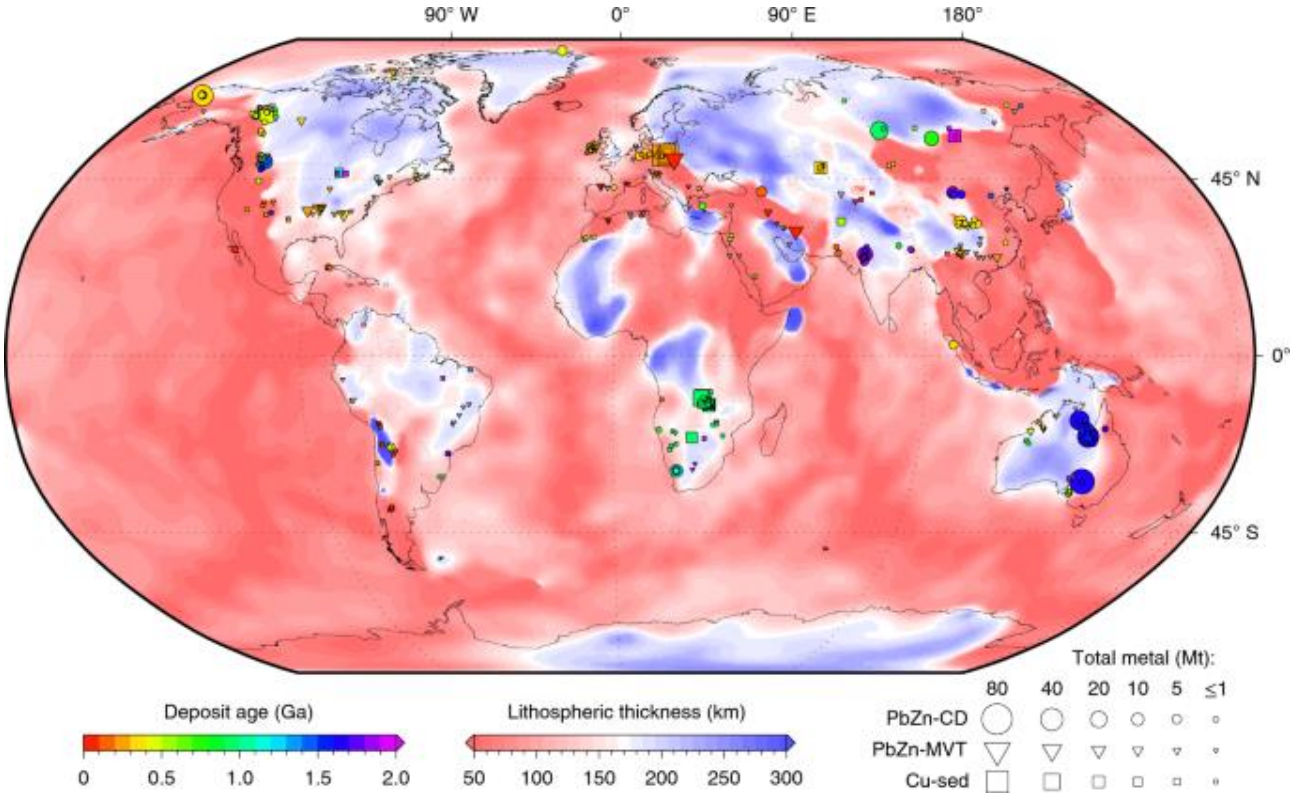

Figure 5. Modelling of Lithosphere global thickness by the CSIRO and known mineral deposits demonstrating the number of prospective covered basin margins in Australia (Hoggard et al, 2020).

The Gawler Basin has long been known as having many analogues with the Central African Copperbelt and the potential to host major deposits. Considerable exploration has so far not defined significant mineralisation in these sequences. Potential however is still high and the Geological Survey of South Australia has recently reconstructed the basin through time and is defining further targets for explorers (Fabris, A 2022). Having the data available for these reconstructions is key to finding the basement margins, structural traps with potential reductants. These concepts are key to understanding this district in flat lying deposits.

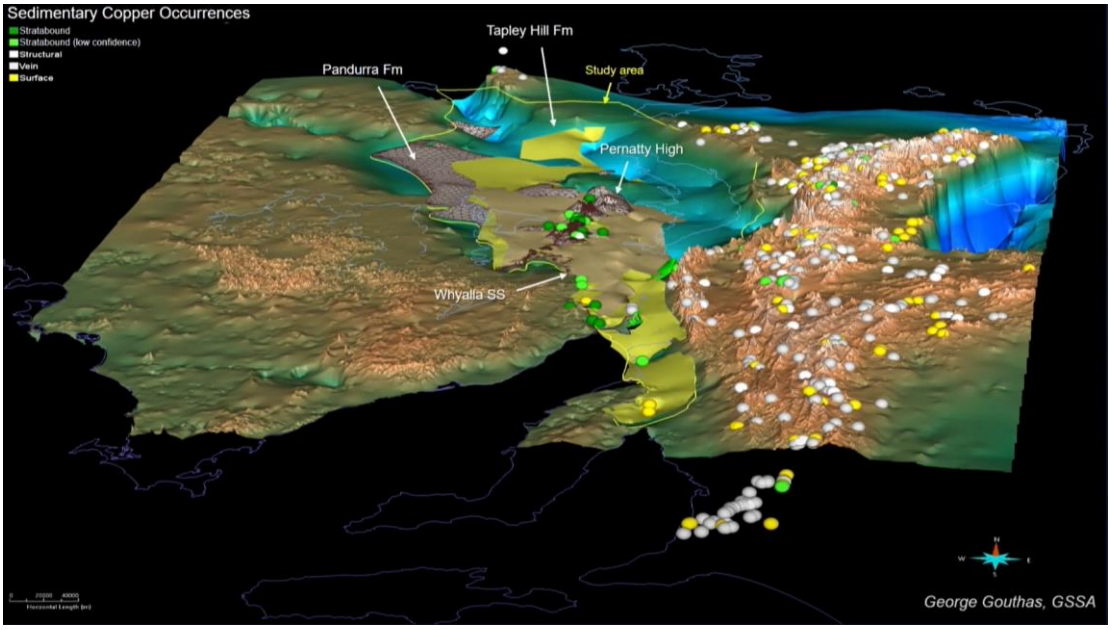

Figure 6. Basin evolution of the Gawler Craton being unravelled by Geological Survey of South Australia with basin reconstruction through time in 3d (Fabris, A 2022)

Highly improved SeaSat data has also been a great advance in mapping the depth to basement across the NT and WA. The McArthur Basin, NT hosts known large Zinc sedex deposits, copper is also present in the basin at the RedBank deposits with over pressured breccia pipes containing high grade copper in the matrix. These indicate a fertile copper basin and despite the significant outcrop extent further potential to discover the a large flat lying deposit is excellent.

The Greater McArthur basin, NT has had little exploration including the North Arunta, Georgina Basin, NT where shallow cover has meant that these potentially mineralised basins have been unexplored historically. First principle mapping is required, utilising petroleum data, advance SeaSat data and aeromagnetics.

The Paterson province, WA contains the Nifty and Maroochydore deposit demonstrating copper depositing in the system. Exploration is hampered by the Permian glacial cover that means geochemistry and electrical geophysics are not effective. The province however has large areas with less than 150m of cover and are very prospective for large deposits. New technologies are required to effectively explore under these glacial clays.

CONCLUSIONS

Sedimentary Copper Deposits have been significant copper producers for hundreds of years and are now more important than ever due to their relatively small environmental and social footprint to develop compared to the largest production deposit style of porphyry copper deposits that are frequently large open pit deposits in the Pacific Ring of Fire..

The Central African Copper belt continues to produce new discoveries with the largest deposit of all Kamoa found in the last ten years. Greater understanding of the mineralising system and large regional geophysical surveys are unlocking the belt. Where access and mine development is possible like the Kalahari Copperbelt in Botswana and Namibia new discoveries are being made under shallow cover and this is expected to continue with increased understanding and data collection. Other belts like the Sullivan belt are restricted due to tenement and political systems in the USA.

A number of basins worldwide have the potential to be larger producers with increased understanding driving exploration further under cover and needing greater understanding of the processes required to precipate significant copper in one location. Access to these areas for exploration is variable but good jurisdictions with low population densities will be prime targets for discovery of new mining regions.

Australia has a number of basins, especially in the Northern Territory where cover rocks are hindering exploration but will be increasingly targeted for large systems. Belts such as the McArthur River, Northern Territory, Gawler Craton, South Australia and the Paterson Province in West Australia are a focus for finding new giant style deposits. These will take significant persistence and funding to discover these deposits beneath cover as they are not conducive to geochemistry or electrical geophysics.

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REFERENCES

Aston Bay Holdings (TSXV:BAY) website, Sorm Copper Project (2022) http:// astonbayholdings.com/projects

Black Butte Copper website, 2021 https://blackbuttecopper.com/

Fabris, A., 2022 Sediment-hosted copper in SA: Could South Australia host deposits like the Central African Copperbelt. Geological Survey of South Australia Discovery day.

Gilchrist G, 2020 Discovery, geology, and controls on mineralisation for the world class stratiform copper deposit at Kamoa-Kakula, DRC. GSSA Talk. April 2022

Hoggard, M, Czarnota, K. Richards F amd Huston DL, (2020) Global distribution of sediment-hosted metals controlled by craton edge stability. Nature Geoscience 13 (7):504-510

McGowan, R.R., Roberts, S. & Boyce, A.J. (2006) Origin of the Nchanga copper–cobalt deposits of the Zambian Copperbelt. Miner Deposita 40, 617

Milton. J., Hickey K, Gleeson S.(2020) Ore forming fluids at the Coates Lake SCC deposit, Redstone, NWT, Canada. Mwale Symposium Presentation SEG.

Noronex Resources (ASX:NRX) website (2022) https://www.noronex.com.au/

Sandfire Resources (ASX:SFR) website (2021) https://www.sandfire.com.au/site/About/company-overview

Valentaa R, D.Kempb, J.R.Owenb, G.D.Corderc, and É.Lèbreb., 2019, Re-thinking complex orebodies: Consequences for the future world supply of copper. Journal of Cleaner Production 220 816-826

Wesby. T.F., 2020 Taking Copperbelt thinking to other Basins. Mwale Symposium Presentation SEG.