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EVAPORITE BRINE-RELATED POTASH: A MINERAL SYSTEMS ANALYSIS

M Clarke

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Cover image: Journey to the centre of the Kimberley (© 2010 PL Schubert)

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Abstract

Potassium is a critical nutrient for plant growth and vital for agriculture. Potash deposits are the primary source of potassium. Although stratabound potash deposits provide the majority of the world's potash, potassium-enriched brines contain the most widely defined and in-development potash resources in Western Australia. Here, potash evaporites are obtained via the evaporation of potassium-enriched brines in the mining process. This style of potash mineralization has the advantage of more efficiently producing sulfate of potash, a more valuable and versatile potash fertilizer than the more common muriate of potash.

Potash-rich brines occur in semi-arid and arid zones in Western Australia, where they are closely associated with inland salt lakes, playas and paleovalleys. The Geological Survey of Western Australia performed a mineral systems analysis to define critical and constituent processes controlling evaporite brine-related potash deposit genesis, and mappable proxies for these processes. Critical processes include: (i) scavenging of potassium from source lithologies; (ii) transportation of scavenged potassium from source to trap via surface and groundwater pathways; and (iii) trapping and further enrichment of brines by flow occlusion and evaporative discharge. The Mineral Systems Tree for evaporite brine-related potash demonstrates the link between geological processes and their recommended GIS map layers for exploration.

KEYWORDS: brines, evaporation, evaporite deposits, groundwater, hydrology, mineral exploration, paleochannel, playa lakes, potash, potash deposits, saline water

Introduction

This Record describes the evaporite brine-related potash mineral system in the Mineral Systems Atlas (MSA). Unlike many of the other systems covered in the MSA, the evaporite brine-related potash system has had comparatively little study from a mineral systems perspective (Mernagh et al., 2016). Furthermore, evaporite brine-related potash systems in Western Australia have several distinct characteristics from those elsewhere in the world owing to different geology and climate. As such, the most influential mineral system models in a Western Australian context have been by Mernagh (2013) and Mernagh et al. (2016), with Magee (2009) and English et al. (2012) providing models more exclusively for Australia's inland groundwater systems.

For context, a brief overview of potash uses, varieties and deposit types is provided; followed by a description of the evaporite brine-related potash mineral system; and then a summary of the critical mineralization processes and mappable proxies. The Appendix provides a short summary of current and historical potash exploration in Western Australia. A mineral systems model is summarized in graphic form as a Mineral Systems Tree. Further information about GIS map layers constructed for the evaporite brine-related potash mineral system may be found in the online Guide to the Mineral Systems Atlas (www.dmirs.wa.gov.au/mineralsystemsatlas).

The information in the Guide and Atlas is likely to evolve and be updated, based on improvements in our understanding about this mineral system and additions of related geoscience data to the GSWA databases.

Mineral Systems Atlas

The MSA is an interactive GIS-based platform that collates and delivers map-based geoscience data layers filtered to be specifically relevant to understanding and exploring for mineral deposits in Western Australia (www.dmirs.wa.gov.au/mineralsystemsatlas). MSA content is systematically defined by applying the mineral systems concept advocated by Wyborn et al. (1994) and McCuaig et al. (2010). The premise of this concept is that mineral deposits will only form and remain preserved where there has been a spatial and temporal coincidence of critical earth processes (geodynamic setting; lithosphere architecture; fluid, ligand and ore component reservoir(s); fluid flow drivers and pathways; depositional mechanisms; post-depositional processes), and that the occurrence of these critical processes might be recognized from mappable geological features expected to result from them. These geological features ('targeting elements' or 'geological proxies') can be extracted as digital map layers from geoscience datasets and may be used in GIS-based prospectivity studies.

Different mineral systems (e.g. Fraser et al., 2007) are analysed to define mappable geological proxies for critical mineralizing processes. Such analyses draw on in-house knowledge, existing literature and collaborations with subject-matter experts. Data used can be derived from publically available GSWA geoscience databases and other government, academic or industry sources. To further highlight, isolate or derive mappable proxies, these data then undergo suitable manipulation and processing, such as structured queries, interpolation and cartography. Queries operating on certain GSWA geoscience databases will be dynamically linked to the primary database, thus proxy map layers will automatically update when new data are added to the primary database. If present, this characteristic will be mentioned on the relevant layer's MSA guide webpage. Users can be confident that the 'dynamically updated' layers contain the latest available data. Layers that are not dynamically updated are considered static and may not be updated on a regular basis, although are included where deemed useful, for example for regional context.

Potash overview

Potassium, along with nitrogen and phosphorus, is a critical nutrient for plant and crop growth. This nutrient is normally supplied as agricultural fertilizer in the form of various potassium salts, collectively called potash. As such, potash is considered essential for agricultural industries and global demand for potash continues to increase (FAO, 2019). Despite the necessity of this mineral for food production, and known occurrences within the country, Australia is not yet self-sufficient in the production of potash (Geoscience Australia, 2014; Senior et al., 2021). This criticality of potash has led to efforts by government agencies to provide pre-competitive datasets to aid in the exploration for this resource (Mernagh, 2013; Geoscience Australia, 2014; Beardsmore et al., 2021).

Potash as fertilizer comes in two main products: muriate of potash (MOP), which is potassium chloride (KCl), and sulfate of potash (SOP), which is potassium sulfate (K_2SO_4). MOP is easier to produce than SOP, due to MOP's similarity to the evaporite stratabound potash ores of sylvite and sylvinite, and it therefore forms the bulk of global potash production. MOP, although used extensively on grain crops, is not suitable for chloride-intolerant agricultural crops such as many fruits and vegetables (National Organic Standards Board Technical Advisory Panel Review, 2007). For these crops, SOP is the preferred fertilizer, and this crop versatility gives it a higher value. Production of SOP from MOP usually requires the energy-intensive Mannheim process, which uses sulfuric acid and heat to produce the SOP with hydrogen chloride (HCl) as a byproduct (Highfield Resources, 2016). Nitrate of potash, which is potassium nitrate (KNO_3), is another valuable fertilizer. However, it is not produced directly from mining or evaporative processes on an industrial scale, and thus not covered further. A summarized flow chart of potash types is presented in Figure 1.

Almost two-thirds of global potash mine production in 2019 was from Canada, Belarus and Russia (U.S. Geological Survey, 2021). The potash deposits supplying this production are stratabound and halokinetic (structurally deformed stratabound) potash-bearing evaporite types. These deposit styles are present mainly in intracratonic basins and account for 75% and 15% of global supply, respectively (Zientek et al., 2010). The dominant ore mineral assemblage within these deposits is sylvite (KCl) and minor (<6 wt%) carnallite ($KMgCl_3{\cdot}6H_2O$) with significant halite (NaCl) gangue (Zientek et al., 2010). Once refined into MOP, further processing into SOP is required via the Mannheim process. Besides evaporites, potash has been economically extracted from other solid phases such as glauconite or alunite; although these types of mineralization require intensive refining to produce purer forms of potash (Border and Sawyer, 2014; Clarke, 2014; Jena, 2021).

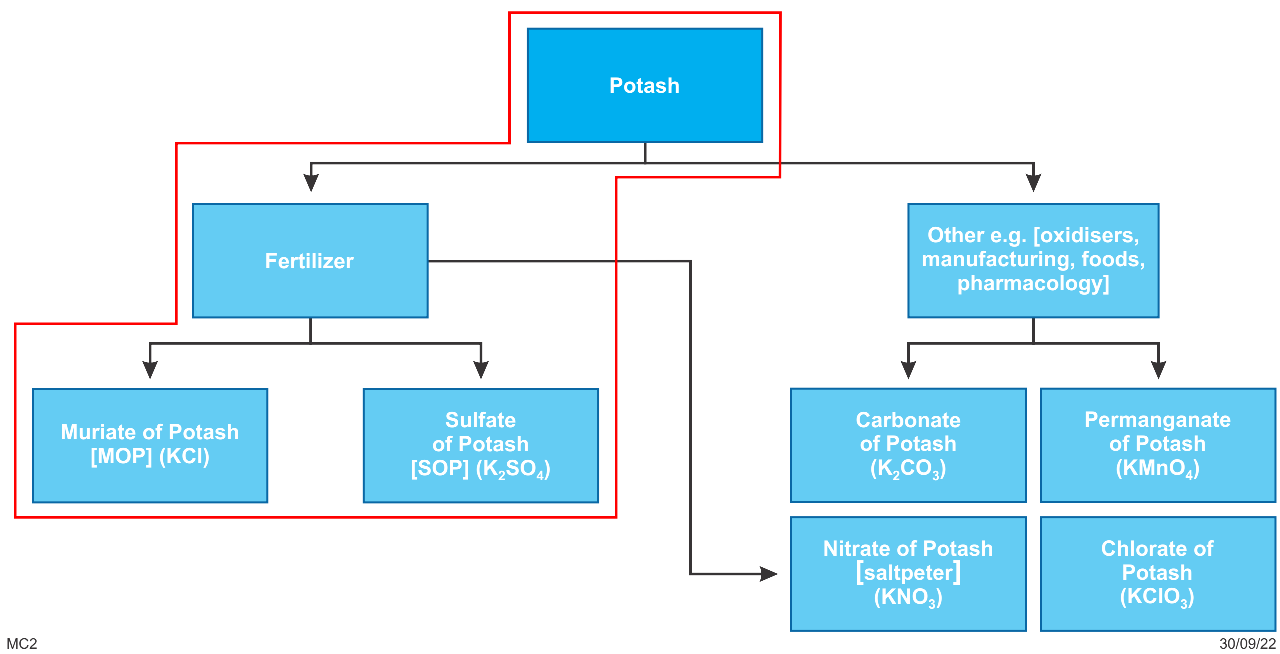

Figure 1. Flow chart of potash types, divided between those used primarily for fertilizer and derived from mining or evaporation processes (bordered in red), and those used for other purposes. Although nitrate of potash is sometimes used as fertilizer, it is not directly produced through mining or evaporative processes at an industrial scale

In contrast to most global potash production, which is from 'hard rock' stratabound sources, potash can be extracted from brine or brine-related processes such as evaporation of inland and seawater derived brines, or the extraction of alunitic clays from acidic salt lake environments. The focus of this Record is on the formation of inland potassium-enriched brines that are near the surface within salt lakes, playas or paleovalleys. These brines form the resource for extraction of potash via onsite evaporation in the mining process. Compared with other forms of potash mining, this method has the disadvantages of relying on climate for evaporation and requiring larger tracts of land for extraction and evaporation operations. However, this method has a significant advantage in the economic production of SOP due to the chemistry of the brines, specifically the presence of sulfate. Along an evaporation circuit, halite will precipitate first leaving behind a brine enriched in potassium and sulfate, from which potassium sulfate minerals such as kainite ($KMgSO_4Cl{\cdot}3H2O$) and schoenite ($K_2Mg(SO_4)_2{\cdot}6H_2O$) can be precipitated (Salt Lake Potash Ltd, 2016). This can significantly reduce the cost of refining an SOP product. Figure 2 shows the different potash mineralization types.

Evaporite brine-related potash mineral system

Within Western Australia, the evaporite brine-related potash mineral system is associated with inland salt lakes, playas and paleovalleys. In this system, the potassium is predominantly sourced from the dissolution of potassium-bearing minerals from the surrounding lithologies, then transported along surface and groundwater pathways with the source of the water flux being rainfall or groundwater (English et al., 2012; Border and Sawyer, 2014). Potassium is then concentrated in salt lakes, playas or paleovalleys, either as soluble minerals or within brines of neutral to high pH. This is in contrast to coastal systems where salts and water are predominantly of marine origin, or to acidic salt lake systems where potassium-rich sulfates, such as alunite and jarosite, precipitate (English et al., 2013; Clarke, 2014). The evolution and geological history of salt lakes and paleovalleys are beyond the scope of this Record, although have been covered extensively by Magee (2009), English et al. (2012) and Mernagh (2013). This Record provides an overview of the subject from a mineral systems point of view; covering the critical mineralization processes of sources, pathways and traps, and mappable proxies.

Mineral system sources

The majority of the potassium in inland salt lakes, playas and paleovalleys is scavenged and transported from surrounding lithologies by meteoric and groundwater fluids that feed into the system's pathways and traps (Orris, 2011; Bastrakov et al., 2013). These lithologies are typically acidic to intermediate igneous rocks, although potassium may also be sourced from older evaporites and continental sedimentary rocks (Orris, 2011; Bastrakov et al., 2013). Within the igneous lithologies, weathered orthoclase, microcline, biotite, leucite

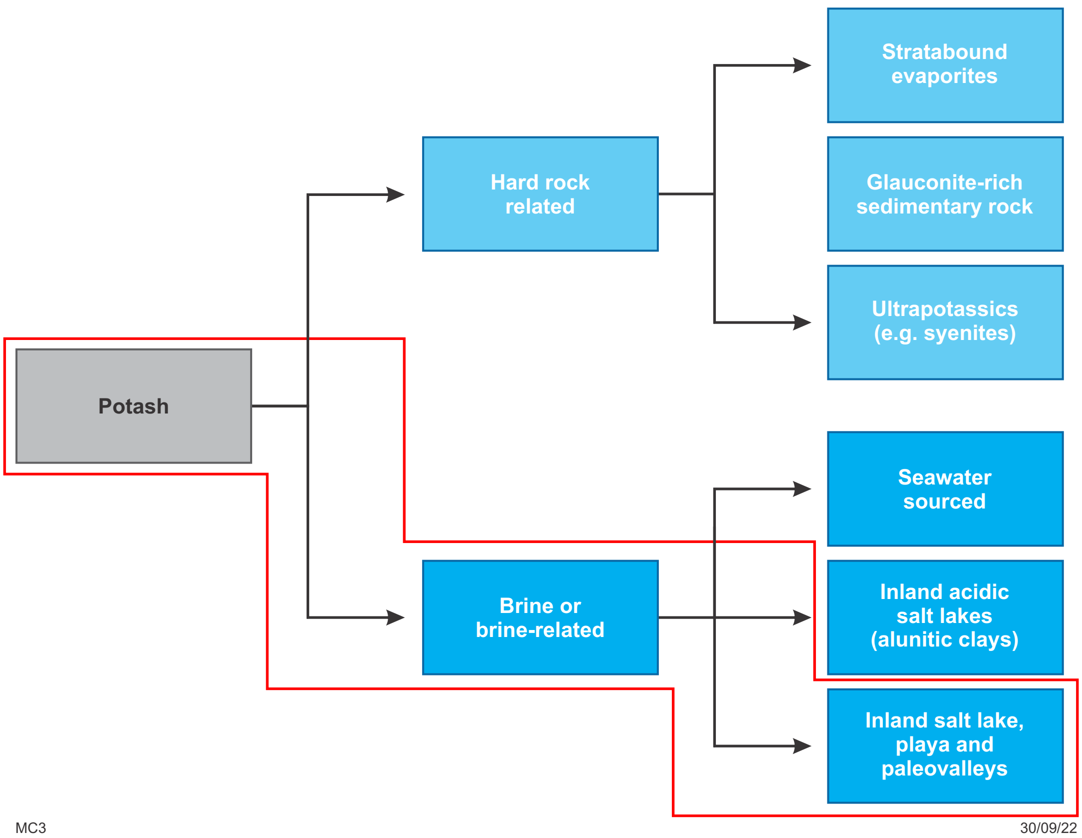

Figure 2. Flow chart of potash deposit styles categorized by the mineralization's host environment, divided between those in hard rock lithologies and those related to brines. Items bordered in red are the focus of this Record

and nepheline are the main providers of potassium (Orris, 2011; Bastrakov et al., 2013). Continental sedimentary rocks such as arkosic or glauconitic sandstones would also likely be important potassium contributors when present in the system. Similarly, older potassium-rich evaporites could not only be a source of potassium via minerals such as sylvite, but also of sulfate from minerals such as gypsum (Orris, 2011; Mernagh, 2013).

Prospective igneous and sedimentary source lithologies are abundant at or near the surface throughout much of Western Australia, especially in the Yilgarn Craton. Stratabound potash-bearing evaporites are less defined in Western Australia, although trace amounts have been intercepted at depth in drill holes within the Canning, Southern Carnarvon and Officer Basins (Wells, 1980; Peiris, 2004). Stratabound potash has been postulated as a contributor to known Western Australian brine-related potash systems, including in diapiric form (Mernagh et al., 2016; Reward Minerals Ltd, 2022).

The maximum source distance and the total available source potassium required for a brine-related potash deposit are unclear. Potassium-bearing fluids could possibly be transported over long distances and enrichment processes that concentrate the potassium can happen over millions of years (Orris, 2011; Mernagh, 2013). These characteristics of the system could allow a potash deposit to form a significant distance from highly potassic sources, or from a larger collection of less potassic-enriched sources, over a range of time periods. What is more fundamental and critical for the system is that these sources, and their related pathways and traps, occur within a closed basin or a basin with sufficient flow occlusion, responsible for the entrapment and enrichment of potassium (Orris, 2011; Mernagh, 2013; Mernagh et al., 2016).

Mineral system pathways

The transport of potassium from source to trap can happen via several processes, including subaerial, surface and subsurface pathways. Although rainfall is important in maintaining suitable fluid flux for surface and subsurface pathways (Rosen, 1994), it can also be a transport mechanism. Continental rainfall has been recorded as enriched in potassium when compared to seawater (Junge and Werby, 1958; Caritat et al., 2019). This is likely due to airborne dust derived from source lithologies, although can also be from burning biomass emissions (Caritat et al., 2019). Rainwater samples from several Australian locations in Crosbie et al. (2012) have shown a potassium chloride ratio at least 10x that of seawater (Caritat et al., 2019). This indicates that rainfall can be a contributing transport mechanism for potassium. However, given that rainfall can be dispersed over large areas, further pathways such as surface and subsurface hydrological features are considered more significant mechanisms for transport to system traps.

Some rainwater is transported towards traps via gravity-driven surface flow (Mernagh, 2013). However, given the arid climate and ephemeral nature of surface hydrology in much of Western Australia's interior, groundwater flow and the associated pathways play the most significant role in transporting potassium from source to trap. In addition to meteoric sources, groundwater may be derived from interstitial water in sediments or basinal and hydrothermal fluids (Rosen, 1994). Basinal and hydrothermal fluids and their related conduits (e.g. faults) have been hypothesized as having a significant contribution to playa and brine systems when they exist within active rift and transtensional strike-slip basins (Hardie, 1990). Given that Western Australia has relatively low tectonic activity, it is unclear how influential tectonic-related conduits are to its brine-related potash systems.

Near-surface weathered, fractured and possibly faulted bedrock aquifers connected to paleovalleys and basin traps could provide a pathway for meteoric water to enter into a brine-related potash system. English et al. (2012) details several examples where the shallow bedrock aquifers are hydraulically connected to paleovalley systems. Major structural zones of fracturing and faulting in the bedrock can produce significant hydraulically transmissive aquifers (English et al., 2012). These aquifers are more commonly the host for recent rainfall when compared with the deeper paleovalley aquifers (English et al., 2012). Importantly, these aquifers are an interface for water to leach potassium from source rock, further enriching the groundwater (Mernagh, 2013).

The most significant pathways for the Western Australian brine-related potash system are paleovalleys. These features encompass not just the paleochannel (or 'thalweg'), but can also include the former valley landforms of overbank deposits, floodplains and river terraces (Magee, 2009; English et al., 2012). Australian arid zone paleovalleys are mostly considered to be Cenozoic, at least in terms of infill, although some may have a geomorphic history as far back as the early Paleozoic (Magee, 2009). Given this long fluvial, or even glacial, history, their geometry can vary widely; between less than one kilometre to several kilometres in width, to over 100 metres in depth and from tens to hundreds of kilometres in length (English et al., 2012). Paleovalley coverage across Australia's western and central arid zones is extensive, linking many source regions with traps, such as salt lakes and playas (Fig. 3).

Despite these arid-zone paleovalleys rarely functioning as surficial drainage, they still represent an active groundwater system (Magee, 2009). Compared to adjacent weathered and fractured basement aquifers, paleovalleys usually have a higher hydraulic conductivity and storage capacity (Magee, 2009). Throughflow and storage is likely the greatest in sand and gravel facies, which commonly appear towards the bottom or middle of the paleovalley's stratigraphy (Magee, 2009; English et al., 2012). These facies can be highly variable along strike of the paleovalley, and can only be accurately determined via across-strike drilling transects (Magee, 2009); although geophysical techniques such as electromagnetics (EM) or gravity may also be useful (Roach et al., 2014). The groundwater will typically evolve towards higher salinity as it progresses from fractured bedrock and tributary paleovalleys, to trunk paleovalleys and finally the traps (Magee, 2009). This happens due to the low flow gradients and multiple opportunities for throughflow occlusion, forcing water towards the surface by the hydraulic head, which in turn leads to evaporative discharge, increased salinity and playa development (Magee, 2009). Paleovalleys with more effective throughflow will tend to have lower salinities, and smaller and fewer playas (Magee, 2009).

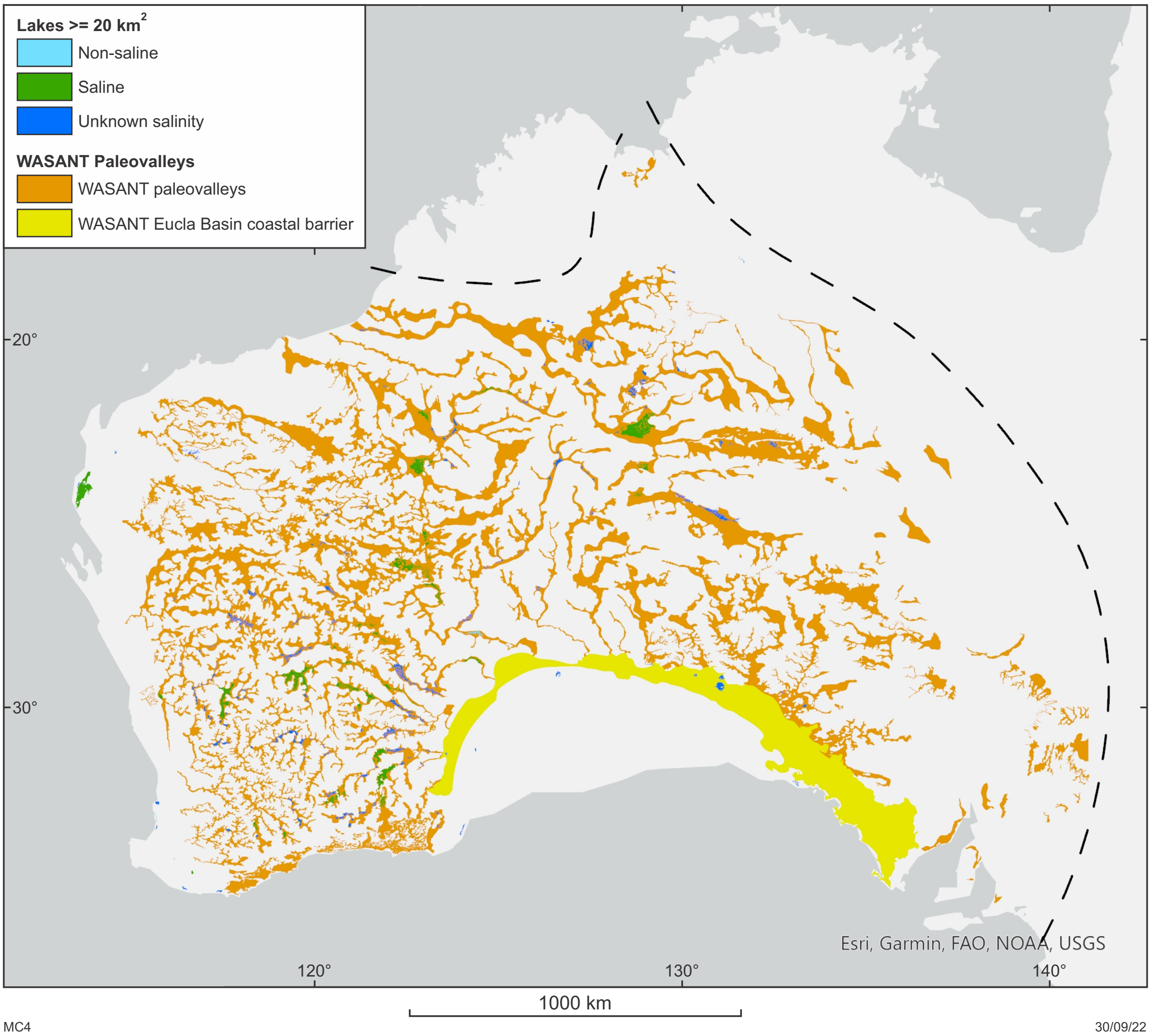

Figure 3. WASANT Paleovalleys and their relation to lakes ≥ 20 km^2 (with salinity status) across Western Australia, South Australia and the Northern Territory. The eastern limit of interpretation is shown by the dashed line. Derived from Bell et al. (2012)

Mineral system traps

For inland Western Australian salt lake systems, the predominance of groundwater in conjunction with the intense arid climate (i.e. evaporation far exceeds rainfall) is perhaps more significant for brine evolution and trapping than hydrological basin closure (Mernagh et al., 2016). Near-surface groundwater processes create an apparent hydraulically closed system, even if underlying through-flowing aquifers exist (Mernagh et al., 2016). An example of this is the aforementioned increasing saline evolution of groundwaters within paleovalleys. Although these features can be a pathway for groundwater, if throughflow occlusion is significant, traps of relatively stagnant and highly saline groundwater will form. As stated earlier, the hydraulic head will force water towards the surface, allowing for evaporative discharge and brine enrichment (including potassium cations) and, in the case of a stagnant pool, potentially lead to the development of a playa (Magee, 2009).

Flow occlusion within paleovalleys can simply be due to the preserved down-valley gradient feeding into a basement depression. However, other mechanisms can also cause hydraulic occlusion. Facies changes, reduced aquifer cross-sections, and precipitation of low permeability and porosity deposits (e.g. silcrete) are some internal paleovalley occluding mechanisms (Magee, 2009). Should occlusion lead to playa creation, the resultant brine pool concentrates less saline groundwater flow towards the playa margins, preventing brine seepage from the playa and further down-valley flow (Bowler, 1986; Magee, 2009; Mernagh, 2013). This can become a steady-state process and help enlarge the brine pool laterally and vertically, only being disrupted by either higher rainfall causing surface water accumulation in the playa, or by an increase in aridity lowering the water table (Magee, 2009; English et al., 2013).

Cenozoic tectonics may have also played an important role in groundwater flow occlusion and playa creation at multiple scales. Due to low relief and flow gradients, even subtle tectonic deformation could affect groundwater systems (English et al., 2013). Although faulting can act as a pathway, it can also cause a lithological block in groundwater flow, creating traps for subsurface flow regimes not immediately apparent from surface topography (Clarke et al., 1998; Magee, 2009; Mernagh, 2013). Halotectonics may have also had significant influence on potash-related playa formation within arid Western Australia (Mernagh, 2013; Mernagh et al., 2016). Kumpupintil Lake (Lake Disappointment) and Lake Mackay have been interpreted as sites of dissolved and subsided salt diapirs (English et al., 2012, 2013).

Vectors to hypersaline brine traps can have obvious surface expressions, such as a large playa or an abundant series of playas within a paleovalley (Magee, 2009). Other vectors may require subsurface imaging using techniques such as EM or gravity and, ultimately, drilling. However, hypersalinity is not a guarantee of economic potassium enrichment. As such, brine-related potash exploration should also seek to understand the available source lithologies within a catchment, the possible pathways from source to trap, and how these and other geological and climatological factors will affect the hydrogeochemical evolution of the groundwater.

Critical mineralization processes

Features of the evaporite brine-related mineral system are summarized as a table of critical processes (Table 1) and as a more detailed Mineral Systems Tree, which is a graphical representation of the important components of the mineral system analysis. Mappable proxies in the lower section of the Mineral Systems Tree represent recommended GIS map layers that will inform the development of the MSA and drive future collection of data relevant to the exploration for potassium-enriched brines.

Table 1. Critical processes for the evaporite brine-related mineral system

Critical process	*Description*
Source	Scavenging of potassium from country rocks by meteoric waters
Pathway	Transportation of potassium-bearing fluids from source to trap, predominantly by groundwater systems
Trap	Formation of potassium-enriched brine pools in salt lakes, playas and paleovalleys, mainly via evaporative discharge

Three critical processes have been identified for evaporite brine-related potash mineralization. Their associated mappable proxies are discussed here in more detail.

Critical process 1: source

Scavenging potassium from potassium-rich source rocks is the first essential step to enrich meteoric fluids. Three main types of source rock include: felsic and intermediate igneous rocks; sedimentary rocks such as potassium-rich sandstones, siltstones and related metamorphic rocks; and other evaporites. Exposed potassium-rich lithologies can be directly detected via airborne radiometrics. Surface mapping can also indicate the presence and extent of outcropping fertile lithologies. These lithologies can be further validated and assessed with geochemical data from surface sampling or drilling. Subsurface stratabound potash evaporites, though rarely observed in Western Australia, have been suggested as a source for enriched brines. Known trace occurrences have been detailed in Wells (1980) and in exploration reports.

Critical process 2: pathway

Efficient scavenging requires suitable fluid flow and permeability pathways to facilitate the transportation of potassium from the source rocks to the trap. These pathways can present as geological structures such as weathered zones, faults or jointing; hydrological and geomorphological features such as surface drainage and paleovalleys; or as eolian and meteorological processes. During transport within these pathways, the meteoric fluid is ideally further enriched by evaporative discharge when at the surface or near-surface levels. Mapped surface hydrology and catchment areas convey more obvious pathway locations and flow directions. However, even though concealed, saline-enriched groundwater pathways can be imaged using airborne electromagnetics, presenting as gradients of increasing conductivity from source to trap. Interpreted depth-to-basement and paleovalley maps can assist in identifying these concealed pathways. Hydrogeochemical data from wells and bores may also indicate fluid pathways in a similar fashion, showing an increasing trend of total dissolved solids or elemental values. Mapping of shear zones, faults, jointing and diapirs can also highlight prospective pathways for both near-surface waters and upwelling brines. Finally, climatological data such as rainfall and prevailing wind directions can inform whether optimal conditions for meteoric fluid recharge and dust transport are present. For brine enrichment en route to a trap, arid to semi-arid conditions are ideal, as they allow for a high evaporation to rainfall ratio, and long evaporative discharge phases, which are essential for groundwater chemical evolution (Bowler, 1986).

Critical process 3: trap

Ultimately, transported potassium-enriched meteoric fluids must be concentrated. Hydrological traps can be present in both closed and open basins within Western Australia. In these areas, flow occlusion and evaporative discharge must be sufficient to allow enrichment of the water's potassium concentration to economic levels (usually >3000 mg/L K). Flow occlusion can occur via topographic or basement lows, and expresses at the surface as salt lakes and playas, or in the subsurface as brine pools within paleovalleys and under playas. As mentioned in the pathway section above, arid and semi-arid zones are most conducive for brine evolution. The evaporation to rainfall ratio for known larger Western Australian brine deposits averages 12 to 13, with a relative potential evaporative concentration (PEC) index (see Bowler, 1986) average of approximately 2300. Figure 4 shows the relationship between the evaporation and rainfall ratio, and the PEC index, for brine-related and non-brine

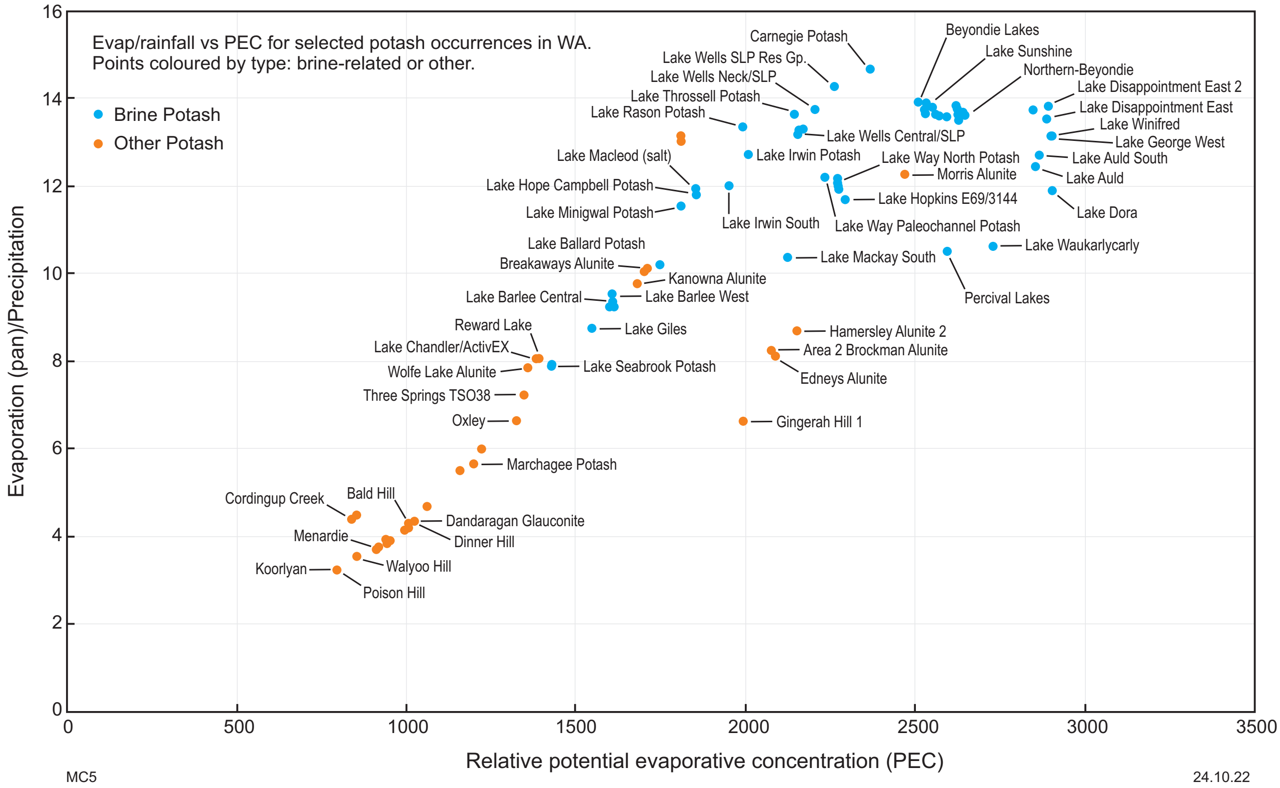

Figure 4. Relationship between the evaporation to rainfall ratio and the PEC index (a relative measure for potential groundwater loss) for potash occurrences in Western Australia. Brine occurrences are in blue, with non-brine occurrences in orange. Higher grade and tonnage deposits for evaporite brine-related deposits, such as Beyondie and Kumpupintil (Disappointment) Lake, plot in the top right corner of the graph. Occurrence names are derived from MINEDEX site names

potash occurrences in Western Australia. Detection methods for concealed traps are similar to those mentioned for pathways; regions that have higher electrical conductivity, or hydrogeochemical samples with higher total dissolved solids (TDS) and potassium values, are indicative of a trap.

Conclusions

This Record summarizes the mineral system for evaporite brine-related potash, with a focus on Western Australia's inland paleovalley and playa systems. In this context, potash refers to potassium sulfate (K_2SO_4) also known as sulfate of potash (SOP). This SOP is refined from evaporite minerals such as kainite ($KMgSO_4Cl \cdot 3H_2O$), schoenite ($K_2Mg(SO_4)_2 \cdot 6H_2O$) and carnallite ($KMgCl_3 \cdot 6H_2O$), which are extracted from evaporated potassium-enriched brines sourced from paleovalleys and playas. Geological processes controlling potassic enrichment of brines are complex, involving interplay between climate, source geology, tectonics, weathering, surface and ground hydrology, precipitation–dissolution reactions and, potentially, hydrothermal fluids (Mernagh et al., 2016).

Links between geological, hydrological and climatological processes involved in the genesis of evaporite brine-related potash include: (i) scavenging potassium from source rocks by groundwater; (ii) transportation and en route enrichment of potassium in groundwater via interaction between geological and hydrological structures in an arid climate; and (iii) trapping potassium-enriched brines in paleovalleys or playas. The constructed Mineral Systems Tree (Fig. 5) for evaporite brine-related potash presents a list of recommended GIS map layers for exploration.

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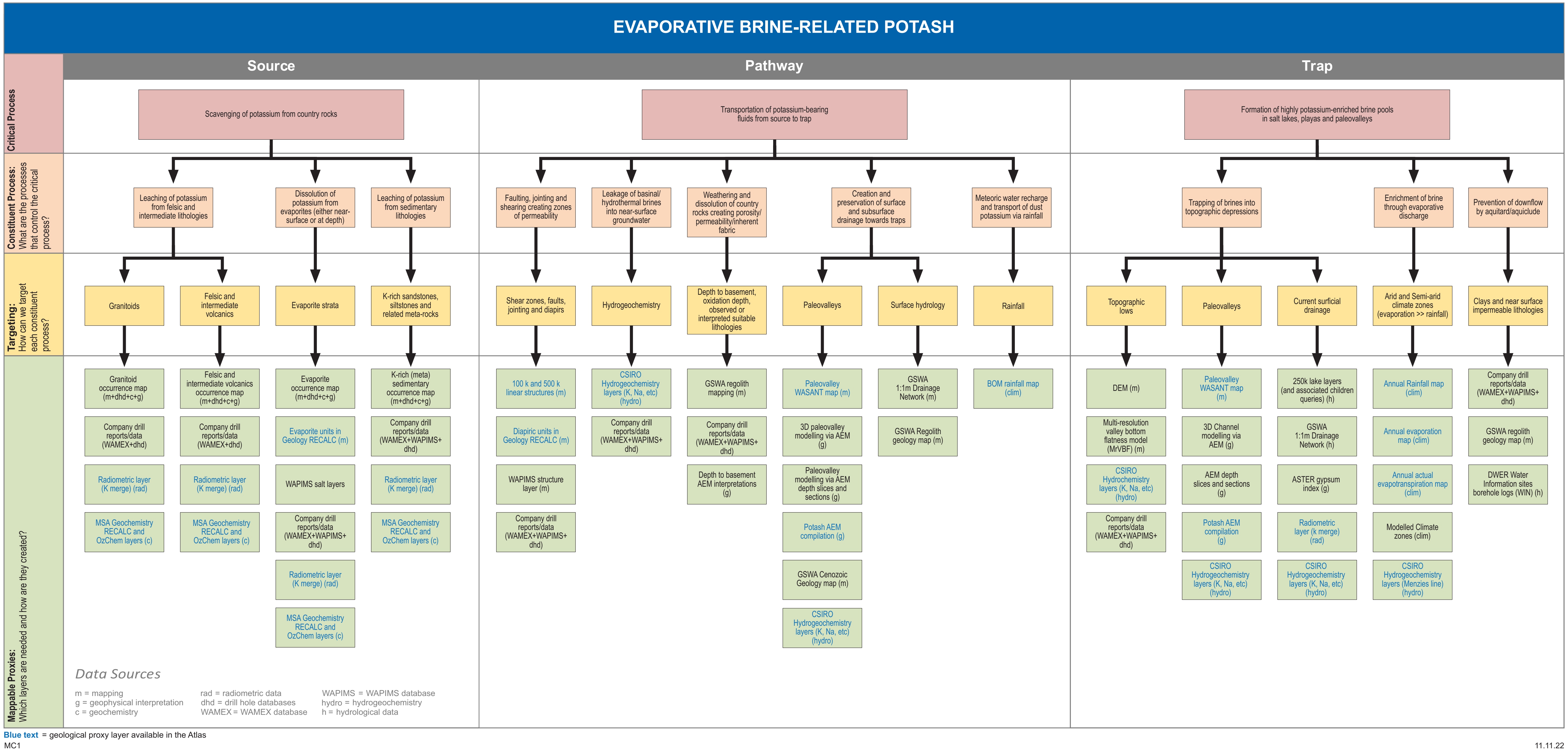

Figure 5. The Mineral Systems Tree for the evaporite brine-related potash mineral system shows the links between the critical and constituent processes, and how these processes relate to their mappable proxies and GIS layers

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Appendix

Potash – past and present projects in Western Australia

Historically, potash production within Western Australia has been from alunite-rich clay deposits within acidic saline playa lakes in the Yilgarn Acid Lakes Province (Clarke, 2014). One such example is Lake Chandler, from which 9218 tonnes of crude potash were extracted, predominantly during the Second World War (GSWA, 2020). These alunite-rich clay deposits form within the more arid zones of Western Australia, south of the Menzies Line (Clarke, 2014). Here, the winter rainfall is conducive to the development of hypersaline brines that react with country rocks or aerosols to produce a potassium-enriched, acidic, hypersaline brine (Clarke, 2014). Recently, some industry interest has been shown in Lake Chandler by ActivEx Ltd and Lake Chandler Mineral Pty Ltd, although work has yet to extend past the exploration stage.

Industry focus for potash production within Western Australia is on the potassium-enriched brines deposit style. Exploration for this deposit style has increased rapidly since 2013, stimulated by Geoscience Australia studies into the strategic resource potential of Australian salt lakes (Mernagh, 2013; Mernagh et al., 2016). These projects are focused on the playas and paleovalleys in the arid interior of Western Australia, where climate and brine chemistry are most conducive to SOP production. Of these, the 'Beyondie SOP' project by Kalium Lakes Limited is the most advanced, having produced its first standard-grade SOP in late 2021 (Kalium Lakes Limited, 2021). This style of deposit has shown the most economic and resource potential within Western Australia (GSWA, 2020) and thus composes the majority of the potash projects (Fig. A1).

Other more globally common or unconventional potash mineralization types are also being considered in Western Australia. The 'Dinner Hill' project assessed the feasibility of producing SOP and phosphates from glauconite in the Dandaragan Trough (Source Commodities Pty Ltd, 2021). Oxley Potash is assessing the feasibility of potash extraction from near-surface ultrapotassic lava flows in the Mid West region (Centrex Metals Ltd, 2016). Reward Minerals Ltd, in addition to its 'Kumpupintil Lake (Lake Disappointment) potash-brine' project, is exploring for evaporite potash within the Browne Formation of the Officer Basin (Reward Minerals Ltd, 2022). Reward Minerals postulates that Browne Formation evaporites may be near-surface and could be responsible for potassium and sulfate enrichment of surrounding brine deposits (Reward Minerals Ltd, 2022).

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Figure A1. Map of Western Australian potash projects (GSWA, 2020)

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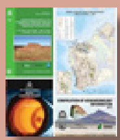

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