The discovery and geology of Sinclair, Australia’s first caesium deposit

David J. Crook*  
Pioneer Resources Limited

Stuart T. Kerr  
Pioneer Resources Limited

Jess A. Booth  
Pioneer Resources Limited

Nigel W. Brand  
Geochemical Services Pty Ltd

Russell Panting  
Pioneer Resources Limited

The announcement of a significant caesium (Cs) intersection (6m at 25.7% Cs₂O) associated with lithium-caesium-tantalum (LCT) pegmatites on the Pioneer Dome was reported by Pioneer Resources Ltd (PIO ASX, 2016a). Follow-up drilling delineated a cluster of pollucite lenses, named the Sinclair Caesium Deposit (Sinclair), with an initial Mineral Resource Estimate of ~10.5 Mt of the caesium ore pollucite with a grade of 17.1% Cs₂O (PIO ASX 2017). Commencement of mining operations was reported on 13th September 2018 (PIO ASX, 2018), less than 2 years after the discovery drill hole.

Pollucite [(Cs,Na)₂(Al₂Si₄O₁₂) 2H₂O] is a rare mineral with a high value due to its high caesium content (~29.66% Cs₂O by weight) which is only known to form in extremely differentiated LCT pegmatite systems. Global supply is very constrained, and world resource estimations are unavailable (USGS, 2019). Caesium metal is sold in limited quantities under confidential contracts, so a true market price is publicly unavailable.

The uses of Cs include in the production of photoelectric cells, energy conversion devices such as fuel cells, magneto-hydrodynamic generators and polymer solar cells. Its main use, however, is in the manufacture of caesium formate brine, a heavy liquid (1.8 to 2.4 g/cm³) used in high-pressure, high-temperature well drilling for oil and gas.

LOCATION AND GEOLOGICAL SETTING

The Sinclair Caesium Deposit is located 35 km north-northwest of Norseman in Western Australia or 125 km south-southeast of Kalgoorlie (Figure 1).

The mine is located within the Archaean Yilgarn Craton of Western Australia, within the Coolgardie Domain of the Norseman–Wiluna Greenstone Belt, host to the large Mt Marion Lithium Project (Mineral Resource Estimate of 71.3 Mt at 1.37% Li₂O; MRL ASX, 2018) and a growing number of LCT-Pegmatite occurrences including Bald Hill and Buldania. The Coolgardie Domain is dominated by two large granitoid

SUMMARY

The Sinclair Caesium Deposit, discovered in 2016 by Pioneer Resources Limited, is Australia’s first mining operation to commercially extract the caesium-rich mineral pollucite. Economic caesium deposits are extremely rare, with only three mining operations having produced commercial quantities of pollucite: the Bernic Lake Mine (or Tanco Mine, Manitoba, Canada), the Bikita Mine (Zimbabwe) and now the Sinclair Mine (Western Australia).

The formation of pollucite only occurs in extremely differentiated lithium-caesium-tantalum (LCT) pegmatites and given their size and rarity, it can be assumed that caesium-rich deposits globally are either challenging to explore for or form suprasingly rarely during the emplacement of LCT pegmatites.

Common with the Bernic Lake and Bikita Deposits, the Sinclair Deposit’s host LCT pegmatite consists of an outer pegmatite wall zone that is coarse grained, and dominated by plagioclase feldspar, muscovite and quartz with other accessory minerals; and an inner core zone composed of quartz, albite (cleavelandite), lepidolite, pollucite, petalite, zinnwaldite, eucryptite, beryl and amblygonite. The core zone is ‘capped’ by a thick (~35-40 m) monomineralic potassium feldspar zone.

This paper will present details on the discovery and geology of the Sinclair Caesium Deposit.

Key words: Sinclair, caesium, pollucite, LCT pegmatite

INTRODUCTION

The announcement of a significant caesium (Cs) intersection (6m at 25.7% Cs₂O) associated with lithium-caesium-tantalum (LCT) pegmatites on the Pioneer Dome was reported by Pioneer Resources Ltd (Pioneer or PIO) on 4th October 2016 (PIO ASX, 2016a). Follow-up drilling delineated a cluster of pollucite lenses, named the Sinclair Caesium Deposit (Sinclair), with an initial Mineral Resource Estimate of ~10.5 Mt of the caesium ore pollucite with a grade of 17.1% Cs₂O (PIO ASX 2017). Commencement of mining operations was reported on 13th September 2018 (PIO ASX, 2018), less than 2 years after the discovery drill hole.

Pollucite [(Cs,Na)₂(Al₂Si₄O₁₂) 2H₂O] is a rare mineral with a high value due to its high caesium content (~29.66% Cs₂O by weight) which is only known to form in extremely differentiated LCT pegmatite systems. Global supply is very constrained, and world resource estimations are unavailable (USGS, 2019). Caesium metal is sold in limited quantities under confidential contracts, so a true market price is publicly unavailable.

The uses of Cs include in the production of photoelectric cells, energy conversion devices such as fuel cells, magneto-hydrodynamic generators and polymer solar cells. Its main use, however, is in the manufacture of caesium formate brine, a heavy liquid (1.8 to 2.4 g/cm³) used in high-pressure, high-temperature well drilling for oil and gas.
domes - the Pioneer and Widgiemooltha Domes - the long axes of which trend north and north-northwest respectively. The younger Binningerie Dyke, an east-west trending Proterozoic dyke, transects the sequence between the Widgiemooltha and Pioneer Domes.

The Pioneer Dome is defined by a granitoid core which has intruded older Archaean gneiss (Fifty Mile Tank Gneiss) and a greenstone sequence. The greenstone sequence comprises a mafic suite (black shale, ultramafic and mafic volcanics, and gabbro intrusions) which in turn has been stratigraphically overlain by a thick sedimentary sequence. Pegmatites have preferentially intruded into the greenstone sequence.

At least 13 clusters of pegmatites, including LCT pegmatites, have been identified along a 20 km strike length on the eastern flank of the Pioneer Dome (Figure 2). The East Pioneer pegmatite corridor comprises a narrow (<1 km wide) suite of mafic rocks trending roughly north-south, faulted up against the Fifty Mile Tank Gneiss. This corridor is dominated by strong north-south cleavages, and along a 20 km strike length on the eastern flank of the Pioneer Dome (Figure 2). The East Pioneer pegmatite corridor comprises a narrow pegmatite dykes occur in both the gneiss and greenstones (Griffin, 1990). To date the only available dating is of the Fifty Mile Tank Gneiss dated at ≥ 2664 ± 5 Ma (Nelson, 1997).

The discovery of pollucite and its subsequent extraction through mining provided Pioneer with a unique opportunity to advance it rare deposit style and provide insights for future exploration for caesium-rich deposits.

**DISCOVERY**

Soil samples were conventionally collected over areas surrounding known pegmatites along the East Pioneer pegmatite corridor. All soil samples were initially analysed utilising an experimental Lithium-Index Calibration developed by Pioneer’s geochemical consultant, Geochemical Services, for use in a field portable XRF (PIO ASX, 2016a). Four acid laboratory analyses were undertaken for areas anomalous in elements associated with LCT pegmatites prior to detailed prospect mapping, rock chip sampling and a decision to drill. Over 7,000 soil samples identified nine high priority and mid-rank targets including the host pegmatite to the Sinclair Caesium Deposit.

The inaugural 5,000 m programme of reverse circulation drilling in mid-2016 (PIO ASX, 2016b) identified high-grade lithium; and importantly included PDRC015, the discovery hole for the Sinclair Caesium Deposit, which returned 6 m at 27.7% Cs2O from 47 m. (PIO ASX, 2016a)

The discovery of pollucite and its subsequent extraction through mining provided Pioneer with a unique opportunity to investigate and advance it’s understanding of the geology, mineralogy and geochemistry of this rare deposit style and provide insights for future exploration for caesium-rich deposits.

**SURFACE GEOLOGY OF THE SINCLAIR PEGMATITE PROSPECT**

Detailed 1:1,000 mapping (Figure 3) and additional detailed soil sampling was completed after the discovery of pollucite at the Sinclair Pegmatite.

Mapping at the Sinclair Pegmatite (PEG008 on Figure 2) recorded a sporadically outcropping, highly fractionated pegmatite body that is emplaced into westerly-dipping mafic and ultramafic rocks. Within the Sinclair Pit it is possible to observe that the pegmatite has intruded at the contact between steeply dipping ultramafic rocks to the west and mafic rocks to the east.

The pegmatite has a strike length in a N-S direction of approximately 800 m and a true width of up to 150 m.

Observable features of the Sinclair Pegmatite at surface include:

- two distinct, low, parallel quartz zone (Gp7 – see Table 1) ridges; with
- a wide, sub-outcropping, blocky microcline (K-feldspar) (Gp4A) zone, infilling between the quartz ridges; and
- poorly exposed pegmatite wall-zones (Gp2) to the west and east of the quartz ridges, including an eastern, approximately 25 m wide sub-unit very rich in muscovite.
• The southern end of the Sinclair Pegmatite is truncated by a right lateral fault. A small syenite intrusive has been emplaced along this structure, and several thin pegmatite stringers feed towards the Sinclair Pegmatite striking ESE, however these show only ‘wall zone’ mineralogy.

The northern end of the Sinclair Pegmatite has not been closed off by drilling.

Figure 3. Sinclair geology map at 1:2500 scale. Note: the pollucite zones (dashed red polygons) do not outcrop and are projected to surface.

SINCLAIR LCT PEGMATITE MINERALS

A feature of the Sinclair Pegmatite, where the Intermediate and Core Zones have formed, are mega-crystals and large monomineralic lenses. Similar lenses are described at the Bernic Lake and Bikita Deposits.

Mono-mineralic lenses of perthitic potassium feldspar, quartz, and pollucite are present, along with near-monomineralic lenses of lepidolite; and mega-crystals of petalite and rarer beryl.

• Potassium feldspar (Gp4) outcrops and has formed as a ‘cap’ apparently overlaying the pegmatite core zones. It is up to 50 m wide, contains >11% K₂O and very low Fe₂O₃ contamination. This zone is sub-divided into an upper (Gp4A - 20-30 m thick) and lower (Gp4X - 5-15 m thick) unit with the lower having a more complex alkali metal enrichment. The upper and lower units are divided by a discontinuous and poddy contaminant zone (<1-5 m thick) of quartz and biotite ± tourmaline, muscovite, beryl, with analyses showing elevated Fe₂O₃ and refractory oxides (e.g. Ta, Nb).

• Reasonably high purity quartz forms prominent outcropping ridges. Subsurface, it occurs as pods, veins and sheets within and adjacent to the potassium feldspar. Quartz also commonly occurs adjacent to pollucite lenses, possibly acting as a reaction-cell wall.

• Lithium is represented in five mineral species, in order of abundance: near mono-mineralic lepidolite, large petalite crystals (up to 20 m long), eucryptite, radiating-zinnwaldite hemispheres and rarer amblygonite. The lithium mineralisation is confined to the ‘core’ zones and is up to 55 m wide and 20 m thick. Petalite and eucryptite mineralisation is often rimmed by secondary pink cookeite (lithium-bearing chlorite), thought to form where final fluid from the fractionated melt has made contact with lithium minerals. Zinnwaldite is closely associated with the lepidolite zones or disseminated within the lower GP6 (mixed zone) near or at the wall zone contact. To date, very minor occurrences of spodumene have been detected using a RAMAN mineral analyser. Spodumene is recorded in significant volumes at Bernic Lake (Stillig et al., 2006) and Bikita (Dittrich et al., 2018), and therefore remains an exploration objective for the Sinclair Pegmatite.

• Caesium is only known to occur in any significant concentration in pollucite, with a “prominent gap in Cs content between pollucite and other mineral associations.” (Dittrich et al., 2018). Pollucite has formed as small (~2-10 m long) mono-mineralic lenses usually adjacent to quartz and almost always rimmed by caesium bearing clays. Pollucite is observed interfingering with lepidolite and quartz, particularly towards the lens base. Veins of lepidolite and cleavelandite are observed cross-cutting pollucite.

• Large beryl crystals occur in several colours, including blue-green aquamarine, pink-orange morganite and white goshenite. Clusters of beryl crystals can form slabs greater than 1 m in diameter. Vertical beryl zoning is evident by depth of the pit, with upper (aquamarine), central (morganite) and lower (goshenite) occurring within the pegmatite core. The large beryl crystals are always associated with the quartz core margins and often on a contact with petalite.

CONCLUSION

The Sinclair Mine provides a rare opportunity to view the resulting crystallography of an extremely differentiated, complex, rare metal pegmatite. Of importance is that this is one of only three commercial-scale deposits where pollucite is observable; with the other two having greatly restricted access – one being an underground operation, and the other situated in Zimbabwe and largely expended. These pegmatites are considered ‘distal’ in terms of their emplacement containing, as they do, a range of lower pressure/temperature and hydrated minerals.

The Sinclair Mine pit walls exhibit a range of large crystals, including a mono-mineralic potassium feldspar zone of several hundred thousand tonnes, overlying the pegmatite core zone with large petalite crystals, lenses of quartz, pollucite, beryl and eucryptite; and large clots of micas such as lepidolite and zinnwaldite. Crystal size in the core zone ranges from banded ‘aplitic’, with deformation resembling that of a semi-
The discovery and geology of Sinclair, Australia's first caesium deposit

consolidated crystal mush - to mega-petalite crystals with at least one in the order of 20 m in length.

Not dealt with in this paper, the mineral crystallisation sequence is observable, and a detailed study is to follow. Very large petalite crystals have apparently formed early, pollucite and quartz together. Lepidolite appears to fill what would otherwise be voids, and possibly concentrically about the pollucite and petalite mineralisation. Many of the minerals are cross-cut by cleavelandite, which could be the last mineral to crystallise.

A good understanding of the relationships between the core zone minerals is considered an important requirement when exploring for further occurrences of pollucite.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the effort of Pioneer Resources Limited staff, consultants and contractors associated with the discovery, delineation and development of Sinclair, Australia’s first caesium mine and the continued and ongoing support from the Pioneer’s Board of Directors.

REFERENCES


### Table 1. Sinclair lithological zones and associated mineralogy.

| GP1: | Border Zone – chilled margin, granitic composition and texture – < 0.5m thick at the greenstone contact |
| GP2: | Wall Zone – albite (plagioclase), quartz, skeletal K-feldspar, muscovite (may include: biotite, microcline, garnet, tourmaline) - includes graphic textured zones. Coarse to very coarse grained. |
| GP3: | Aplitic Zone – aplitic albite - quartz - biotite (and may include: muscovite, Ta-Nb oxides, beryl, apatite, tourmaline) - banded, including intra-layer folding. Observable as a semi-continuous layer along the southern and south-western Stage 1 pit wall. Cross-cut by petalite crystals. |
| GP4A: (KFA) | Upper Intermediate Zone (K) – mega-crystalline perthitic potassium feldspar (microcline) with fine albite intergrowths, which form a 'monomineralic' zone measured in hundreds of thousands of tonnes. Comparatively minor quartz ribs. Internal clots of ‘contaminant’ quartz-biotite occur near the GP4A edges. Uncontaminated GP4A (i.e. KFA) is characterised by high K2O (11.6%), high Al2O3 (18.7%), very low Fe2O3 (<0.03%) and K2O:Na2O ratio (3.62) (deposit-average figures). Confirmed has high ceramic-grade potash feldspar. |
| GP4X: (KFX) | Lower Intermediate Zone (K) – mega-crystalline perthitic potassium feldspar (microcline) with fine albite intergrowths, quartz ribs, and a higher proportion of ‘contaminant’ quartz-biotite clots. Chemical composition generally similar to KFA, however with slightly higher Fe2O3 (<0.03%) and elevated Rb2O (>0.4%). |
| GP5: | Core Petalite Zone (Li) – predominantly large to very large petalite crystals, with adjacent quartz and minor albite (var. cleavelandite) - (plus interstitial eucryptite, cookeite, pollucite, lepidolite, amblygonite, Ta oxides). An Eucryptite dominant zone was discovered during mining, and amblygonite becomes more common towards the footwall of this zone. To date very rare crystals of spodumene have been identified. |
| GP6: | Core Intermediate Zone – a less well defined, mixed zone of albite (var cleavelandite), quartz, minor lepidolite, (may also include: micas, beryl, Ta-Nb oxides, petalite, zinnwaldite, tourmaline) – coarse grained. Cleavelandite often appears to cross-cut other minerals suggesting it is late to crystallise. |
| GP7: | Core Quartz Zone – predominantly quartz (with enclosed or adjacent beryl, pollucite, petalite). Predominantly translucent, pale grey quartz, or rare rose quartz. Distinguished from other darker brown-grey ‘contaminant’ quartz common at contacts, which has elevated Fe and Ta. |
| GP8: | Core Pollucite Zone – pollucite (may be intercalated with quartz, lepidolite, petalite, and cross-cut by albite (var. cleavelandite). Zone flanked by opaque sodic calcium plagioclase. Grades of > 28% Cs2O reported for massive monomineralic pollucite samples. |
| GP9: | Core Lepidolite Zone – dominant lepidolite, with cleavelandite, quartz (may also include: zinnwaldite, beryl, Ta-Nb oxides, tourmaline, rare amblygonite) – with up to 4.5% Li2O reported massive monomineralic zones of lepidolite. |

* (The Gp nomenclature is adapted from the Bernic Lake Deposit codes described in Cerný et al., 1998.)