# Cadia region lead isotope (tank sediment testing) report

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We recognise Aboriginal peoples' spiritual and cultural connection and inherent right to protect the land, waters, skies and natural resources of NSW. This connection goes deep and has since the Dreaming.

We also acknowledge our Aboriginal and Torres Strait Islander employees who are an integral part of our diverse workforce and recognise the knowledge embedded forever in Aboriginal and Torres Strait Islander custodianship of Country and culture.



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# Contents

The Environment Protection Authority (EPA) carried out an independent study to analyse rainwater tank and soil samples around the Newmont gold mine (Cadia Valley Operations) in Central West NSW. The study aimed to measure lead isotopic compositions in tank sediments, soils and potential emission sources from the mine to determine the origin of the lead. Comparisons were made with known lead sources, including the Broken Hill ore body, historically used in Australian products such as leaded petrol and paint.

The study found that lead in soil and tank sediments generally matched natural background levels and lead from Broken Hill. There does not appear to be any measurable influence from the ventilation shafts or tailings facilities on the lead in almost all tank sediment samples.

Results indicated that lead in tank sediments was from a mixture of old leaded products and local soils rather than the mine. The tank sediment samples with the highest lead levels also had lead isotopic compositions that are associated with old paint or building materials. So while the isotope study could not definitively identify the source of lead in tank sediments, evidence suggests it is unlikely to be the Cadia Valley Operations gold mine.

# Background

The community surrounding the Newmont, formerly Newcrest, gold mine (Cadia Valley Operations) has expressed concern that dust from the mine site may be contaminating the surrounding land and domestic water tanks. In response, the NSW Environment Protection Authority (EPA) has carried out an extensive environmental sampling campaign of soil, air, water from water tanks and water tank sediments in the community close to the mine. The aim is to better understand the potential impact of the mine on environmental and human health, to respond to the local community's concerns, and to consider any potential measures for managing exposure.

## Newmont sampling: the Gulson Report

Newmont also undertook an environmental sampling campaign, including the use of lead isotope testing on tank sediment samples. Emeritus Professor Brian Gulson was engaged to prepare an independent expert report on the interpretation of lead isotopes results of collected tank sediment samples (the Gulson Report). The Gulson Report concluded that a portion (14 out of 89) of the tank sediment samples had a lead isotope composition similar to ore sampled from Cadia Valley Operations. Professor Gulson also found that the soil sampled from the region around the mine and the mine ore had isotopic ratios that overlap, as both the natural soil and the ore deposits would be influenced by the same geological processes. Therefore, it does not mean that the ore is the main contributor to the lead in tank sediments but could not be conclusively ruled out and that soil could be a significant contributor. Professor Gulson recommended further characterising the soil, including soil profiles, to evaluate the contribution from natural sources.

## EPA sampling: this report

The EPA has undertaken independent environmental sampling and lead isotope testing to independently assess the sources that might be contributing to lead in tank sediment samples. As well as analysing tank sediments, it has measured the lead isotope composition of surface and sub-surface soils across the Cadia region, to establish natural sources. It has also sampled the potential sources onsite at Cadia Valley Operations (ventilation rise and tailings storage facility) and analysed the lead isotopic composition of those sources.

This report summarises the results of the lead isotopic compositions of local soils, tank sediments and potential emissions sources from Cadia. The aims of the study were to:

- carry out independent lead isotope testing on EPA-collected samples
- characterise the lead isotopic composition of natural soil and specific onsite sources
- determine whether Cadia Valley Operations could be identified as a contributor to lead in tank sediments.

## Lead isotopes

Lead (Pb) has four stable isotopes, three of which are the stable end products of the radioactive decay of a parent element: these three are $^{208}$Pb from $^{232}$thorium; $^{207}$Pb from $^{235}$uranium; and $^{206}$Pb from $^{238}$uranium. These radiogenic lead isotopes (ones created through radioactive decay) increase in abundance over time relative to the amount of lead, uranium and thorium present. The fourth isotope, $^{204}$Pb, is primordial and has not increased in abundance since the formation of the Earth. This allows for lead ores to have their own specific set of isotopic ratios and the age of the ore body to be determined. Where the ore mineralisation is low in lead, the lead isotopic composition of samples of galena (a lead-rich ore, PbS) is measured to represent the 'initial' ratios of the ore at the time it formed. However, this may not be the dominant lead isotopic composition of mined ore resources.

The Broken Hill lead ore body, one of the world's largest, formed approximately 1.7 billion years ago. It has been mined continuously since 1884. The Broken Hill ore signature is well characterised in the scientific literature and still represents the initial ratios. Cadia ore lead isotope ratios have been measured and published by CSIRO (Forster et al. 2011). Samples of galena found at Cadia have been used to determine an age of mineralisation of 438 million years ago (Forster et al. 2011).

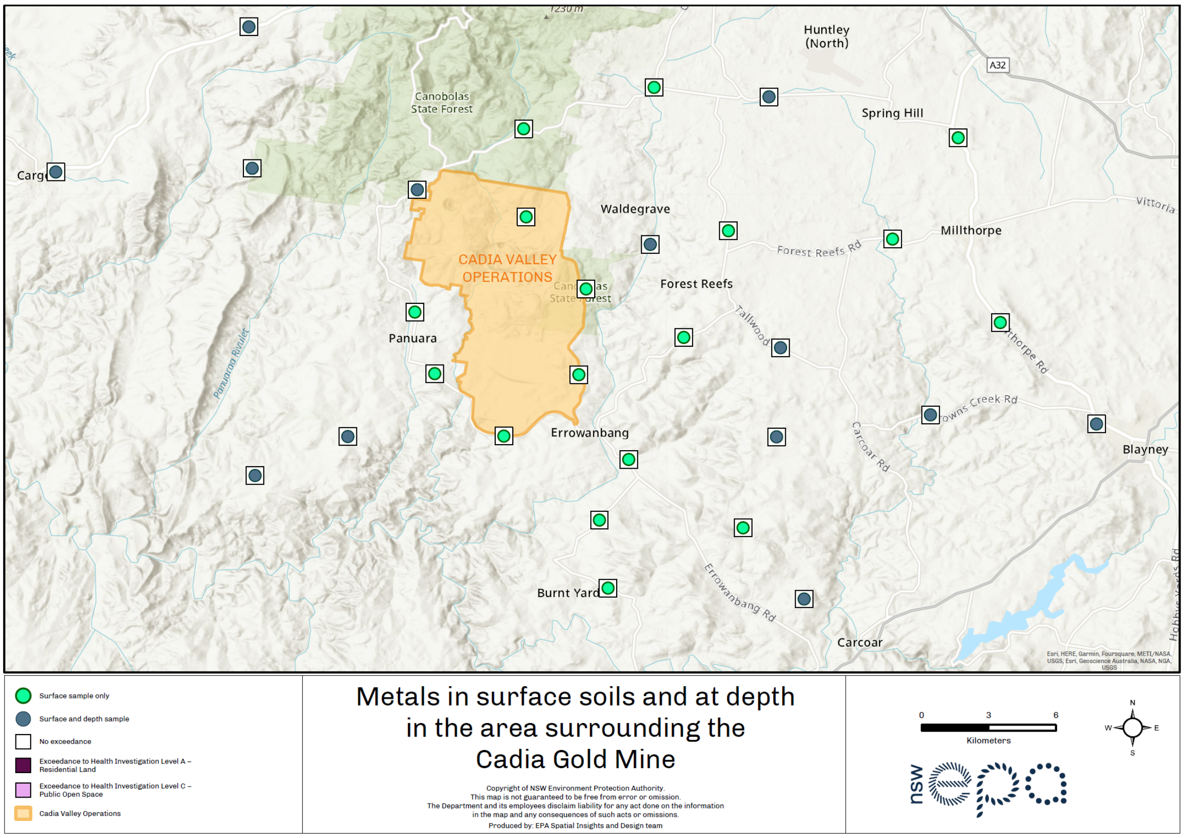
Lead isotopes can also provide unique information on the natural and anthropogenic source inputs and their relative contributions to environmental samples. Where lead originates from more than one source, its isotopic composition will lie on a mixing line between the isotopic compositions of the two sources (end members). The contribution of each source can be quantitatively apportioned with mixing equations. This is most effective where there are large and distinct differences in the lead isotope ratios of the potential sources. Outside of lead mining and smelting locations, Broken Hill ore signatures have been identified in environmental studies due to the predominant use of Broken Hill lead in Australian-produced lead products, including leaded petrol, lead paint and lead arsenate agricultural sprays (Gulson et al. 1981). Soils generally have high radiogenic lead isotopic compositions that reflect their parent rocks, and can easily be distinguished from anthropogenic sources that contain Broken Hill lead (Gulson et al. 1981).

# Samples

## Soil sampling

As outlined in the EPA's soil report (see *References*), 30 sites were sampled within 15 km of the mine (see Figure 1). Thirteen of those samples included a sub-surface soil sample taken at 50 cm depth to represent natural background soils. The lead concentrations of the 30 surface soil samples were 6–21 mg/kg and for the sub-surface soils they were 5–17 mg/kg. All 43 soil samples were analysed for their lead isotopic composition.

**Figure 1 Map showing the locations of soil samples**



## Tank sediment sampling

As outlined in the EPA's sediments report (see *References*), 52 tank sediment samples were collected. Of those, 39 tank sediments from 31 properties were analysed for their lead isotopic composition. Lead concentrations ranged from 5.9 mg/kg to 1600 mg/kg.

As well as analysing the tank sediment samples it had collected itself, the EPA analysed 13 tank sediment samples collected by the community ('community samples'). The lead isotopic compositions from these samples are included only in Figure 4. The EPA does not have enough information about those samples to allow further analysis.

## Mine source sampling

The EPA has analysed the lead isotopic composition of samples from the mine's north tailings storage facility (TSF) and ventilation shaft emission (VR8). This is to determine the lead isotopic composition of specific Cadia Valley Operations sources that have been identified by the community as causing dust offsite.

The lead concentration of the EPA's north tailings storage facility sample was 4 mg/kg, which is consistent with Newmont data of 2–5.3 mg/kg for eight samples (Harrison, 2021). The ventilation shaft emission sample collected by the EPA for lead isotope analysis had a concentration of 26 mg/kg.

## External isotope data

The lead isotopic compositions for Cadia ore used in this report are sourced from high-resolution measurements from the literature (Forster et al. 2011) and Newmont samples measured between August 2022 and January 2023 (Gulson Report, 2023). The literature data used galena (PbS) samples to determine the original or 'initial' lead isotopic composition of the mineralisation. However, the gold and copper ores mined today at Cadia Valley Operations are likely to have different isotopic ratios, reflecting their low lead concentrations and the radioactive decay that has taken place. The recent Newmont data better reflects the current extracted ore, but both sets of Cadia ore data are included in this analysis for context.

Literature values for the Broken Hill ore body are used to represent non-local, non-natural sources contributing to lead in soils and sediments, such as petrol, paint, building materials and other anthropogenic sources of lead.

# Results

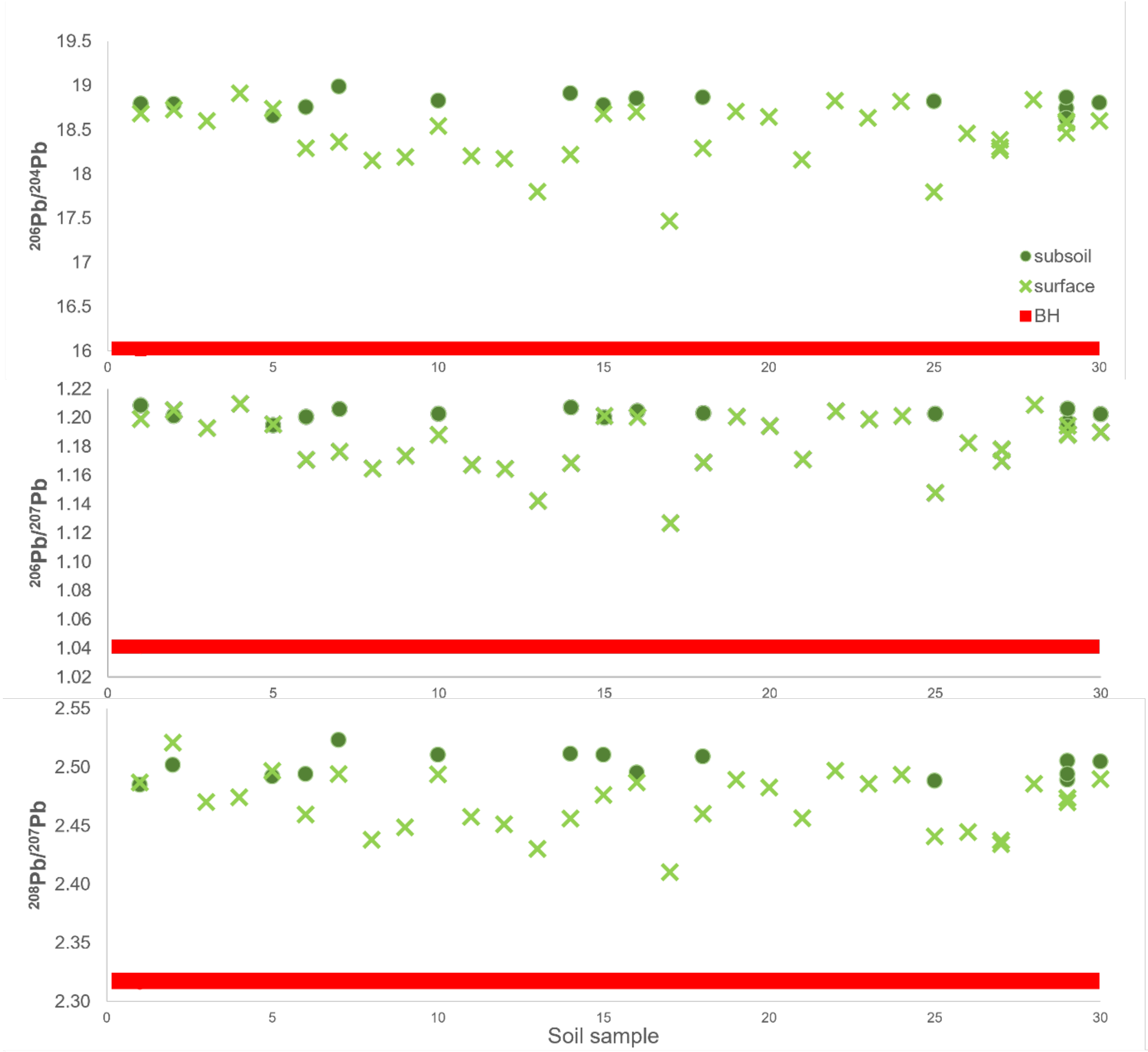
## Soils

Sub-surface soils are representative of the natural background lead isotopic composition of the soils around the Cadia region. Unlike surface soils, they are not affected by external sources such as deposition of air pollution, wastewater, irrigation and fertilisers. Natural background (sub-surface) soils have been thoroughly characterised in this study over a large area. The lead in the background soils is highly radiogenic (arising from radioactive decay), as is expected for natural rock-weathered soils and as measured in other Australian studies (e.g. Kristensen et al. 2016). However, where soil is present in water tanks, surface rather than sub-surface soils would be the major soil contributor, having entered the tanks through wind erosion and dispersion, and human activities.

The soil and rock samples reported on in the Gulson Report are from an isolated, lead-rich region to the west of the Cadia Valley Operations, and have lower lead isotope ratios than the soils measured in this new investigation. The two sets of findings are not contradictory: rather, they indicate the complex geology of the region where older, lead-bearing rocks are still present in specific locations.

While the lead concentrations are low in all collected soil samples, the lead isotopic compositions show that a portion of surface soil samples have a measurably different isotopic compositions to their corresponding sub-surface soils (Figure 2). Some sample matrix heterogeneity is expected and can be seen in the sample triplicate results (when the results from three samples from the same location are compared). Where there is larger variability between the paired surface and sub-surface soils, this is most likely due to the quantifiable influence of leaded petrol (which predominantly used Broken Hill ore) on surface soils: this has been reported in numerous Australian studies.

**Figure 2 Lead isotopic compositions of all soil samples collected around Cadia.**
Soil sample number corresponds to the soil sample number in the EPA's soil report.



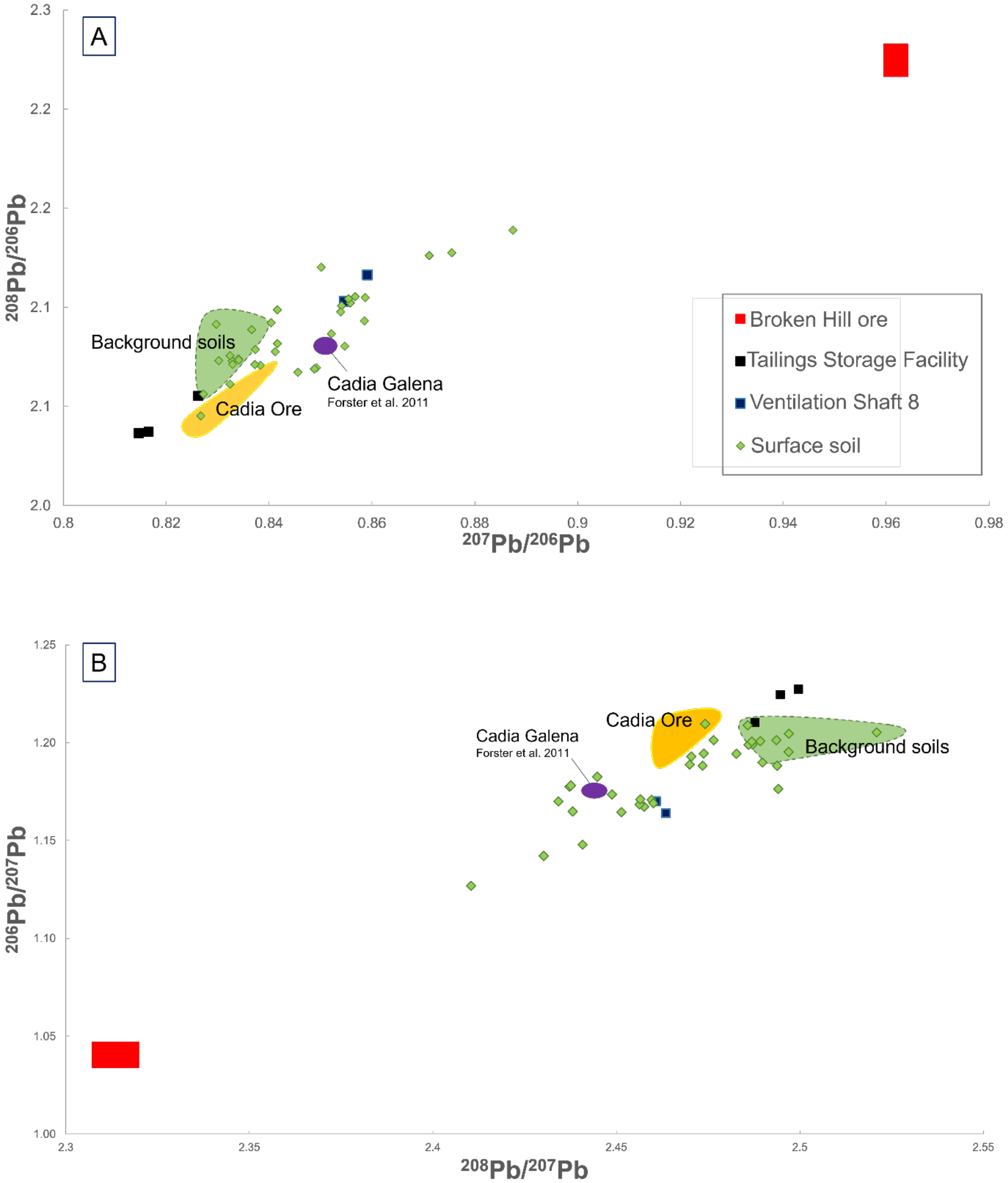

The surface soils show a range of lead isotopic compositions. Some have substantially different lead isotopic compositions from the background soils represented by the sub-surface soils. These surface soils may be more highly influenced by Broken Hill ore or reflect a wider natural variability of the area. The isotopic composition range of the sub-surface soils in Figure 2 is shown in later figures as 'background soils'.

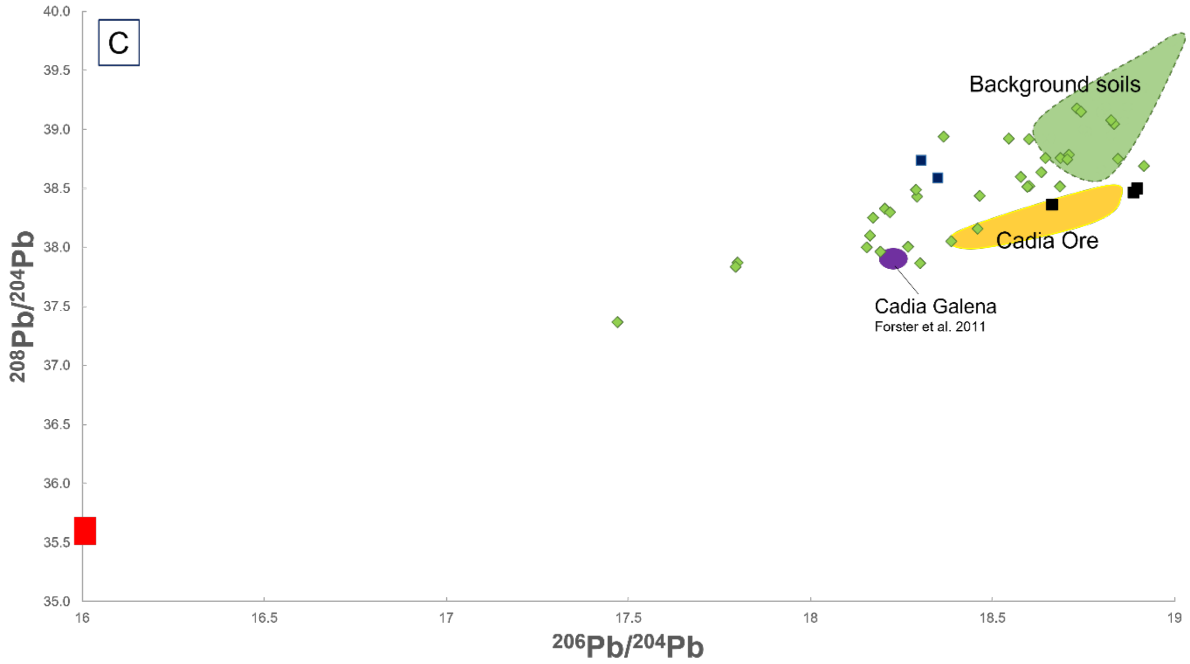
# Identification of potential sources

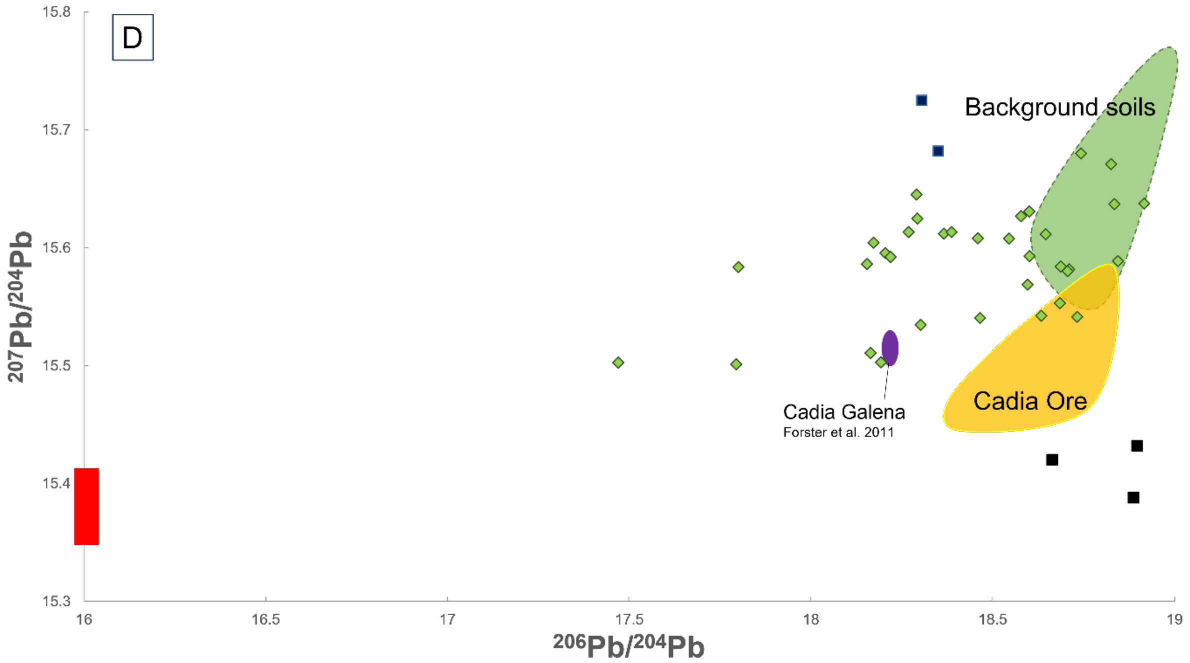
The Gulson Report identified significant overlap between the Cadia ore lead isotopic composition (the 'Ore field') and the soil samples. The similarity of soils to Cadia ore is evident and not unexpected. This has previously complicated the interpretation of the source of lead in tank sediments. The Gulson Report stated that 14 of the 89 'sludge' samples have data lying within the 'Ore field' i.e. overlapping. That does not mean the ore is the main contributor to the lead in tank sediments as the isotopic data suggests that the surface soil could be a significant contributor.

The EPA has specifically considered the individual potential sources from Cadia Valley Operations: ore, tailings storage facilities (TSF) and ventilation shafts (VR8). These have all been separately sampled and analysed for their lead isotopic composition, to provide a greater chance of determining the potential contribution to tank sediment samples attributable to the mine. The local soils and sources from Cadia Valley Operations have lead isotopic compositions that are very similar and overlap (Figure 3). However, the surface soils do not appear to be measurably impacted by deposition of emissions from Cadia Valley Operations (i.e. tailings storage facilities or ventilation shafts). The $^{207}Pb/^{204}Pb$ ratio provides the most separation of local sources, particularly providing a clearer distinction between soil, tailings and ventilation emissions (Figure 3). There is a clear distinction between any possible local source (i.e. soil or Cadia) and anthropogenic sources (e.g. paint, petrol, building materials) represented by the Broken Hill ore signature (Figure 3).

**Figure 3 The lead isotopic compositions (A: $^{208}Pb/^{206}Pb$ vs $^{207}Pb/^{206}Pb$; B: $^{206}Pb/^{207}Pb$ vs $^{208}Pb/^{207}Pb$; C: $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$; D: $^{207}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$) of potential contributing sources**






# Tank sediments

There is a large range of lead isotopic ratios among the tank sediment samples. The spread of isotopic ratios in the sediment samples matches with the results reported in the Gulson Report. The sediment samples range between the lead isotopic composition for Broken Hill ore, representative of various anthropogenic sources (leaded petrol, lead paint, building materials, etc) and the local sources (soil, Cadia ore, tailings, ventilation shafts) (Figure 4 plots A, B, C, D).

The $^{207}Pb/^{204}Pb$ ratio is used to provide the clearest interpretation of whether Cadia Valley Operations is contributing in any measurable amount to the lead in tank sediments.

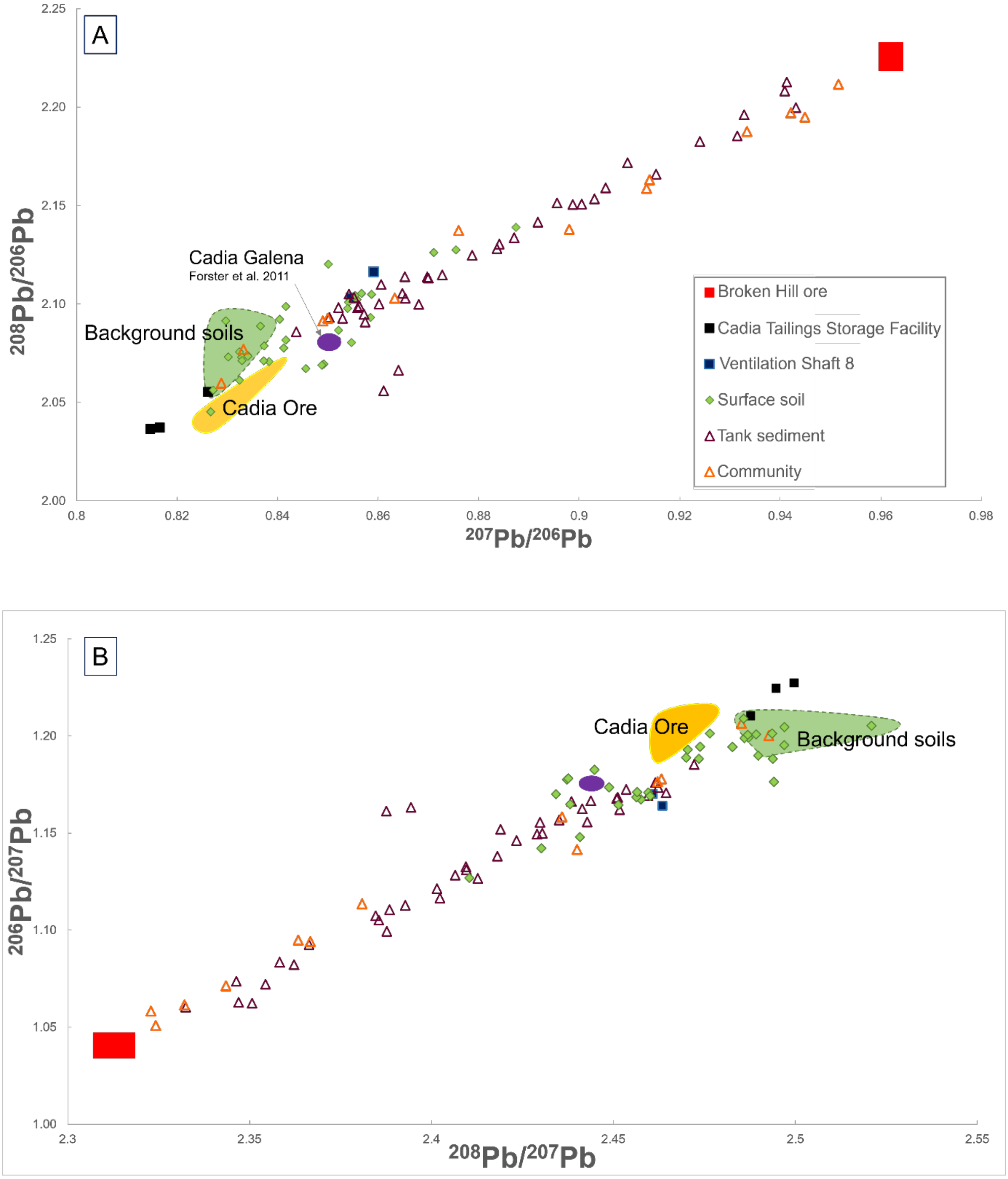
## Tailings

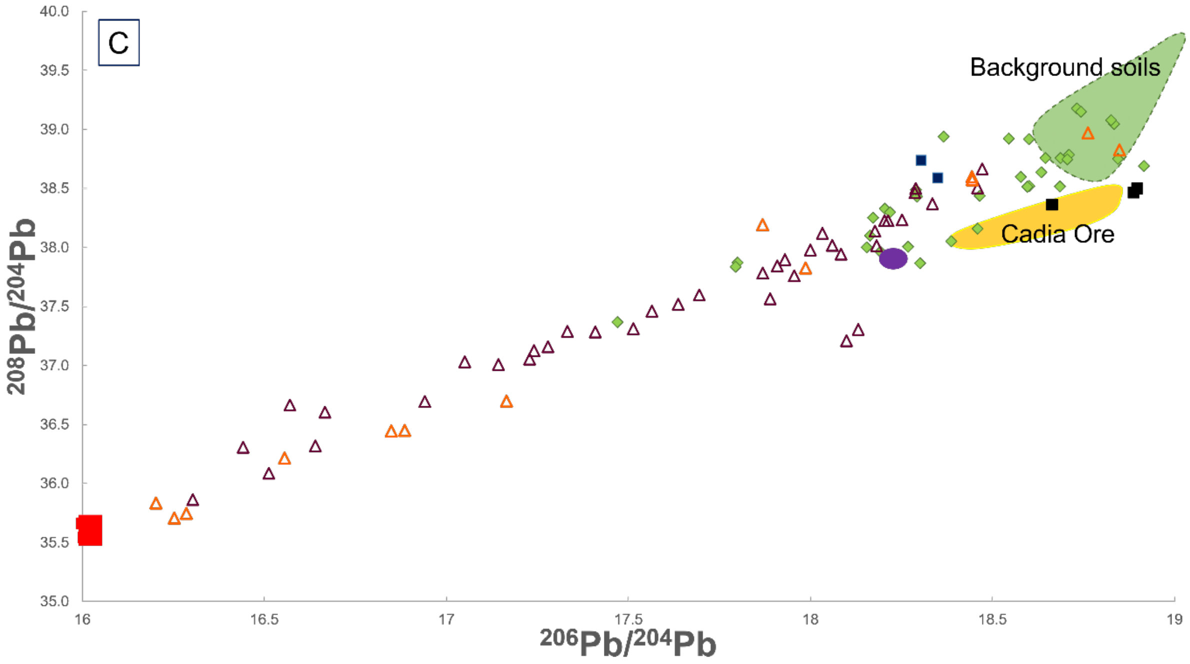
The plot of $^{207}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ (Figure 4 plot B) indicates that the tank sediment samples lie on a mixing line between Broken Hill and soil rather than towards the Cadia tailings. There appears to be no measurable influence from the tailings on all but one of the lead isotopic composition results from tank sediment samples. (This is discussed later in the paper.) It is therefore unlikely that emissions from the Cadia tailings storage facility is the source of lead in tank sediment samples.

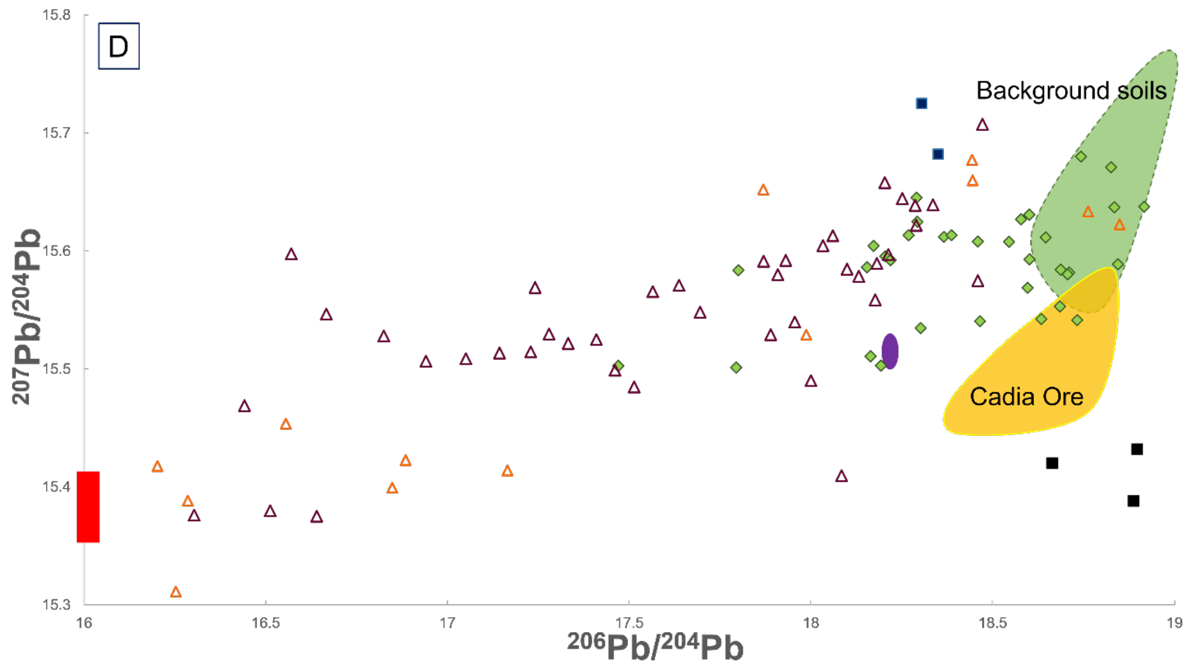
## Ventilation shaft emissions

The lead isotopic composition from the ventilation shaft samples (VR8) lies on the mixing line between Broken Hill and background soils. The VR8 sample generally has an isotopic composition within the range of surface soils, and with a similar lead concentration. The plot of $^{207}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ (Figure 4 plot B) indicates that all but one of the tank sediment samples are not measurably influenced by the ventilation shaft emissions. (This is discussed later in the paper.). It is therefore unlikely that emissions from the Cadia ventilation shafts are the source of lead in tank sediment samples.

**Figure 4 The lead isotopic compositions (A: $^{208}Pb/^{206}Pb$ vs $^{207}Pb/^{206}Pb$; B: $^{206}Pb/^{207}Pb$ vs $^{208}Pb/^{207}Pb$; C: $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$; D: $^{207}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$) of potential contributing sources and tank sediment samples**





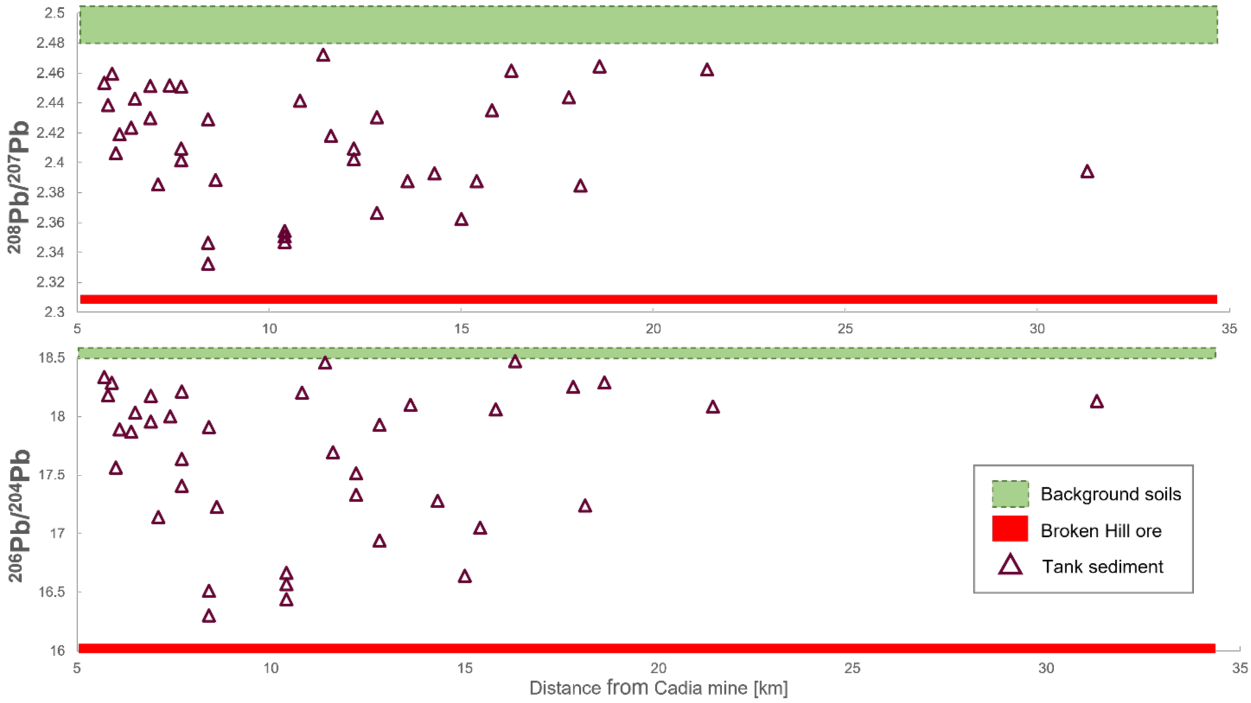




There are two tank sediment samples that, based on their lead isotopic composition alone are not conclusively absent of influence from Cadia Valley Operations. However, these samples were collected furthest from the mine, 16–20 km to the north-east. These properties were also closest to the Great Western Highway, the train line running between Orange and Blayney, and the Orange airport, all of which might be contemporary or historic sources.

## No spatial fallout pattern found

National and international studies of lead (and other metal) concentrations and lead isotopes show a clear spatial fallout pattern originating from a mine when it is the dominant or key contributing source (Gillings et al. 2022; Kristensen and Taylor 2016). In the tank sediments collected by the EPA, the lead isotopic composition doesn't show any spatial relationship to Cadia Valley Operations, which is similar to the natural soil (Figure 5). Similarly, the lead isotopic ratios of the tank sediment samples from the Gulson Report do not show any lead isotopic pattern related to distance from the mine.

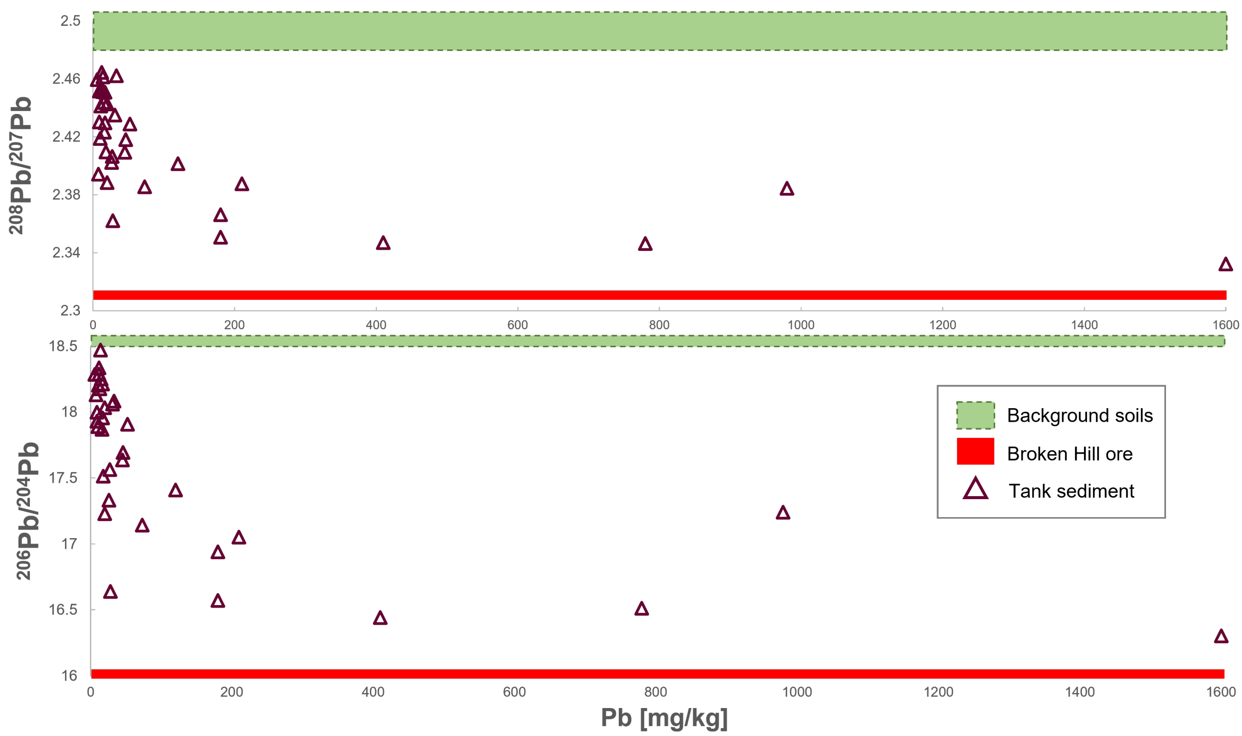
**Figure 5 Distance of tank from Cadia Valley Operations vs $^{206}Pb/^{204}Pb$ in tank sediment samples compared to background soils (green bar) and Broken Hill ore (red bar)**




# Relationship to concentration

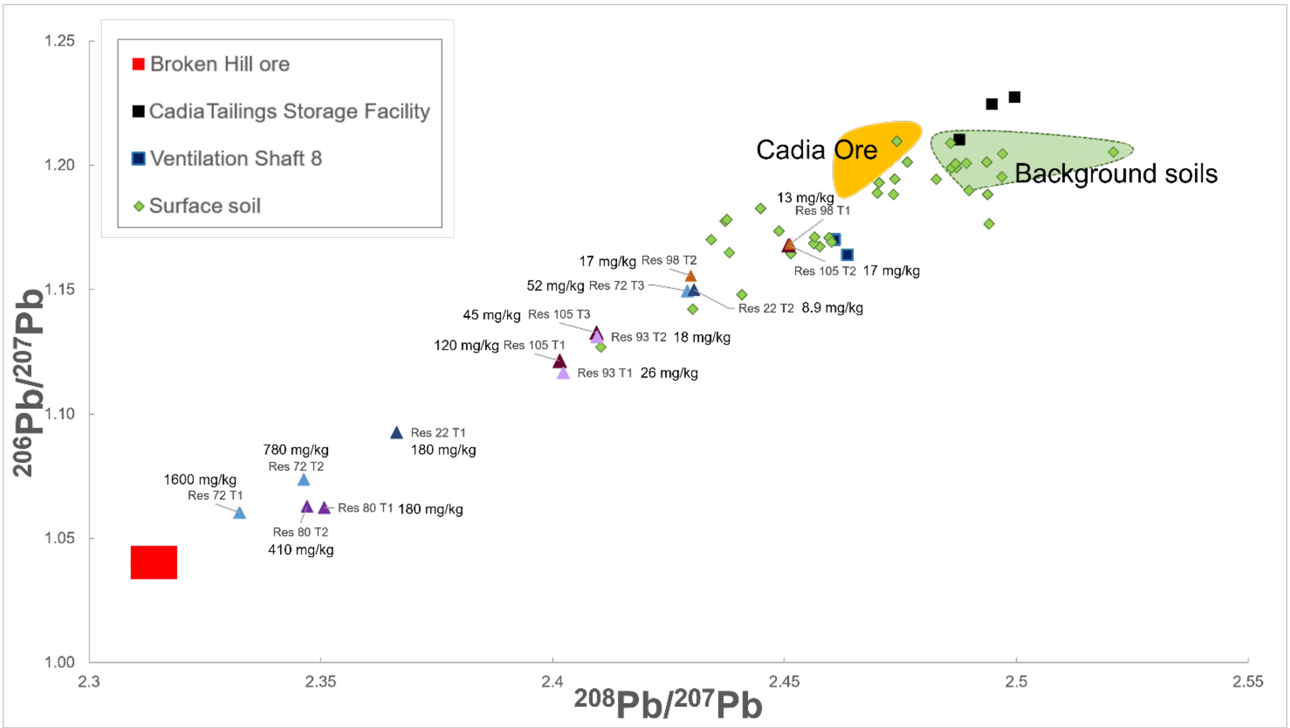
Due to the lead from Cadia Valley Operations having a similar lead isotopic composition to that of local soils, it can be difficult to elucidate between the sources. Figure 6 shows that where tank sediments have a high concentration of lead, the isotopic ratios are very different from those of local soils and Cadia Valley Operations, indicating that neither the local soils nor the mine is the lead source. This is consistent with the low measured lead concentration of soils, tailings and ventilation emissions reported in this study.

**Figure 6 Lead concentration vs $^{206}Pb/^{204}Pb$ in tank sediment samples compared to background soils (green bar) and Broken Hill ore (red bar)**



Where sediment samples were taken from more than one tank at the same property, the lead isotopic compositions and concentrations do not indicate that the mining operations are the cause of high lead concentrations. Multiple tanks sampled at the same property (and therefore influenced equally by distance from the mine) show that as the lead concentration increases, the lead isotopic composition becomes increasing similar to that of Broken Hill ore (Figure 7). This is supported by the lead concentrations of the tailings storage facility and ventilation shaft emissions samples being similar to soil lead concentrations.

**Figure 7 Lead isotopic compositions and lead concentrations of tank sediments at multi-tank residences (res)**




Lead isotopes alone cannot absolutely rule out that emissions from Cadia Valley Operations may be contributing dust to the environment. But the weight of evidence presented in this report indicates that the lead measured in tank sediments in the higher range (above 300 mg/kg) is not predominantly from local soil or Cadia Valley Operations.

# Accuracy and precision of lead isotope measurements

The laboratory (Queensland Government Forensic and Scientific Services) reports a measurement uncertainty of 0.4 %. The lead isotope data was measured on a triple quadrupole Inductively Coupled Plasma Mass Spectrometer (ICP-QqQ-MS). National Institute of Standards Technology (NIST) 2709a San Joaquin soil has been used in numerous scientific studies to demonstrate and evaluate the accuracy and precision of the laboratory isotopic measurements for similar sample matrices (e.g. soil). A sample of the NIST 2709a standard reference material (SRM) was provided as a blind sample to the laboratory.

The data obtained for NIST 2709a from this study ($^{206}Pb/^{204}Pb$: 19.0865; $^{207}Pb/^{204}Pb$: 15.6434; $^{207}Pb/^{206}Pb$: 0.8196; $^{208}Pb/^{206}Pb$: 2.0439) was compared to the published literature for lead isotopes (Rivero et al. 2023, Aung et al. 2004, Souto-Oliveira et al. 2019, Reimann et al. 2011 and Takaoka et al. 2006) and shows good agreement.

A sample of Broken Hill ore, well defined in the scientific literature (Townsend et al. 1998, Cooper et al. 1969, Chiaradia et al. 1997, and Gulson and Mizon 1979) was also analysed and shows good agreement ($^{206}Pb/^{204}Pb$: 16.0648; $^{207}Pb/^{204}Pb$: 15.4623; $^{207}Pb/^{206}Pb$: 0.9625; $^{208}Pb/^{206}Pb$: 2.2270).

Relative percentage differences (RSDs) of triplicate soil measurements were 0.24–0.44 % for $^{207}Pb/^{206}Pb$, 0.21–0.25 % for $^{208}Pb/^{206}Pb$ and 0.27–0.52 % for $^{206}Pb/^{204}Pb$.

# Conclusion

The lead isotopic compositions from the EPA's collected tank sediment samples have been measured to evaluate whether Cadia Valley Operations is a contributing lead source. The EPA has also measured the lead isotopic composition of the soils of the Cadia region and of specific, potentially significant, mine sources.

The lead isotopic compositions of the Cadia ore are similar to those of the natural soils, but there was found to be an identifiable difference between the lead isotopic composition of the tailings storage facility and that of the ventilation shafts. This allows for the lead in the tank sediment samples to be distinguished from contributions from soil and other anthropogenic sources that use Broken Hill lead.

The isotopic compositions of tank sediments are spread between those of two key contributing sources – soils and Broken Hill ore – indicating that soil and anthropogenic sources are the major contributors. The tank sediments with the highest lead concentrations have lead isotopic ratios that are closer to that of Broken Hill ore, which indicates that lead from leaded paint or building materials is the primary source of lead in tank sediments.

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