

# Reconnaissance zircon U-Pb geochronology of the southeastern Olympic Cu-Au Province, South Australia

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Wang Tiangang and  
Zhao Xiaodan

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# **Reconnaissance zircon U-Pb geochronology of the southeastern Olympic Cu-Au Province, South Australia**

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# Reconnaissance zircon U-Pb geochronology of the southeastern Olympic Cu-Au Province, South Australia

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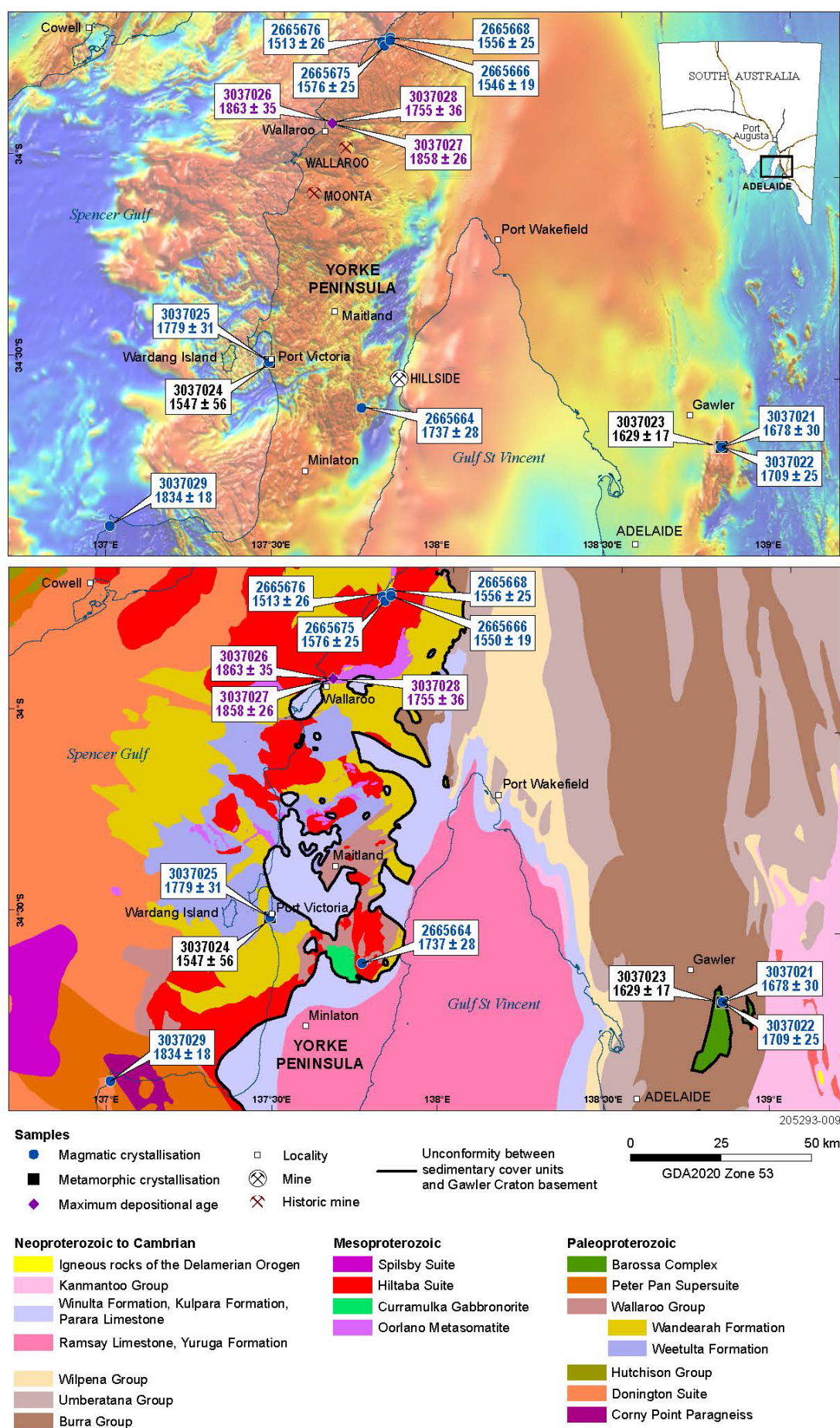
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## INTRODUCTION

The eastern Gawler Craton is the location of the Olympic Cu-Au Province, a world-class metallogenic province known for iron oxide-copper-gold deposits such as Olympic Dam, Prominent Hill and Carrapateena (Skirrow et al., 2007; Reid, 2019). The Olympic Cu-Au Province is a vast region some 600 km in strike length, with several sub-regions of distinctive geology and mineralisation style. The focus of this report is the southern region of the Olympic Cu-Au Province, in particular the geology of the Yorke Peninsula. This region contains the historical Moonta-Wallaroo mining district, the Hillside deposit in the east and a range of other prospects and smaller deposits (Fig. 1; Conor et al., 2010).

This report describes new geochronology and geochemistry collected on samples from the Yorke Peninsula (Fig. 1). The aim of this project has been to characterise the age and chemistry of the crust in this region. The samples selected are from the Barossa Complex, the Proterozoic basement unit of the Adelaide Rift Complex, the Donington Suite, Wallaroo Group and granites interpreted to belong to the Hiltaba Suite (Table 1; Fig. 1). In this way, these samples cover the main stratigraphic units of the Yorke Peninsula region and, in the case of the Barossa Complex samples, the reworked eastern margin of the Gawler Craton. As the samples extend from the oldest (Donington Suite, c. 1850 Ma) to the youngest (Hiltaba Suite, c. 1580 Ma) stratigraphic units, they provide an insight into the crustal evolution of the region through the later Paleoproterozoic and into the early Mesoproterozoic.

The new data has been collected as part of a collaborative project between the Geological Survey of South Australia and the China Geological Survey, Nanjing Center. This is a technical report describing the samples analysed and the analytical results, and provides a brief discussion of their geochronological interpretation. All U-Pb data are provided in Appendix 1 and are available via SARIG <https://map.sarig.sa.gov.au>. Whole rock geochemistry and Sr-Nd isotopic data was also collected on selected samples and is presented in Appendix 2.



**Figure 1. Location of the samples dated in this report.** Samples with respect to total magnetic intensity image (top). Interpreted solid geology across Yorke Peninsula (bottom). Samples are distinguished based on the age type determined from the U-Pb geochronology.

**Table 1. Summary of samples detailed in this report.**

| Sample No.                                                | Location or drillhole name and depth | Latitude | Longitude | Stratigraphic unit             | Description                                                      | Age (Ma)               | Age type                                                |
|-----------------------------------------------------------|--------------------------------------|----------|-----------|--------------------------------|------------------------------------------------------------------|------------------------|---------------------------------------------------------|
| <b>Barossa Complex</b>                                    |                                      |          |           |                                |                                                                  |                        |                                                         |
| 3037023                                                   | Houghton Inlier                      | -34.6805 | 138.8472  | Barossa Complex                | Hematite-altered augen gneiss                                    | 1629 ± 17              | Metamorphic crystallisation                             |
| 3037022                                                   | Houghton Inlier                      | -34.6805 | 138.8472  | Barossa Complex                | Augen gneiss                                                     | 1709 ± 25<br>1638 ± 10 | Magmatic crystallisation<br>Metamorphic crystallisation |
| 3037021                                                   | Houghton Inlier                      | -34.6805 | 138.8472  | Barossa Complex                | Augen gneiss                                                     | 1678 ± 30<br>1650 ± 23 | Magmatic crystallisation<br>Metamorphic crystallisation |
| <b>Paleoproterozoic rocks of Yorke Peninsula</b>          |                                      |          |           |                                |                                                                  |                        |                                                         |
| 3037029                                                   | Berry Bay                            | -34.921  | 137.0114  | Gleesons Landing Granite       | Augen Gneiss                                                     | 1834 ± 18              | Magmatic crystallisation                                |
| 3037025                                                   | Port Victoria                        | -34.505  | 137.4796  | Wardang Volcanics              | Rhyodacite                                                       | 1779 ± 31              | Magmatic crystallisation                                |
| 3037024                                                   | Port Victoria                        | -34.505  | 137.4796  | Renowden Metabasalt Member     | Metabasalt                                                       | 1547 ± 56              | Metamorphic crystallisation                             |
| 2665664                                                   | CUR D5<br>78.5–78.9 m                | -34.6133 | 137.761   | Hiltaba Suite                  | Granite                                                          | 1737 ± 28              | Magmatic crystallisation                                |
| <b>Oorlano Metasomatite</b>                               |                                      |          |           |                                |                                                                  |                        |                                                         |
| 3037026                                                   | Harlequin stone quarry               | -33.9078 | 137.6515  | Oorlano Metasomatite           | K-feldspar dominant alteration                                   | 1863 ± 35              | Maximum depositional age                                |
| 3037027                                                   | Harlequin stone quarry               | -33.9078 | 137.6515  | Oorlano Metasomatite           | Amphibole-Epidote dominant alteration                            | 1858 ± 26              | Maximum depositional age                                |
| 3037028                                                   | Harlequin stone quarry               | -33.9078 | 137.6515  | Oorlano Metasomatite           | Amphibole-Epidote dominant alteration, with chalcopyrite bornite | 1755 ± 36              | Maximum depositional age                                |
| <b>Magmatic rocks of the northwestern Yorke Peninsula</b> |                                      |          |           |                                |                                                                  |                        |                                                         |
| 2665676                                                   | PBD28<br>294–295.4 m                 | -33.7014 | 137.7923  | Spilsby Suite                  | Fine grained granite                                             | 1513 ± 26              | Magmatic crystallisation                                |
| 2665675                                                   | PBD30<br>119.4–120.4 m               | -33.7121 | 137.8001  | Tickera Granite, Hiltaba Suite | Foliated granite                                                 | 1576 ± 25              | Magmatic crystallisation                                |
| 2665668                                                   | KD10<br>187.8–189 m                  | -33.6917 | 137.8173  | Hiltaba Suite                  | Altered granite                                                  | 1556 ± 25              | Magmatic crystallisation                                |
| 2665666                                                   | KD4<br>250.25–251.6 m                | -33.6986 | 137.8168  | Hiltaba Suite                  | Altered granite                                                  | 1546 ± 19              | Magmatic crystallisation                                |

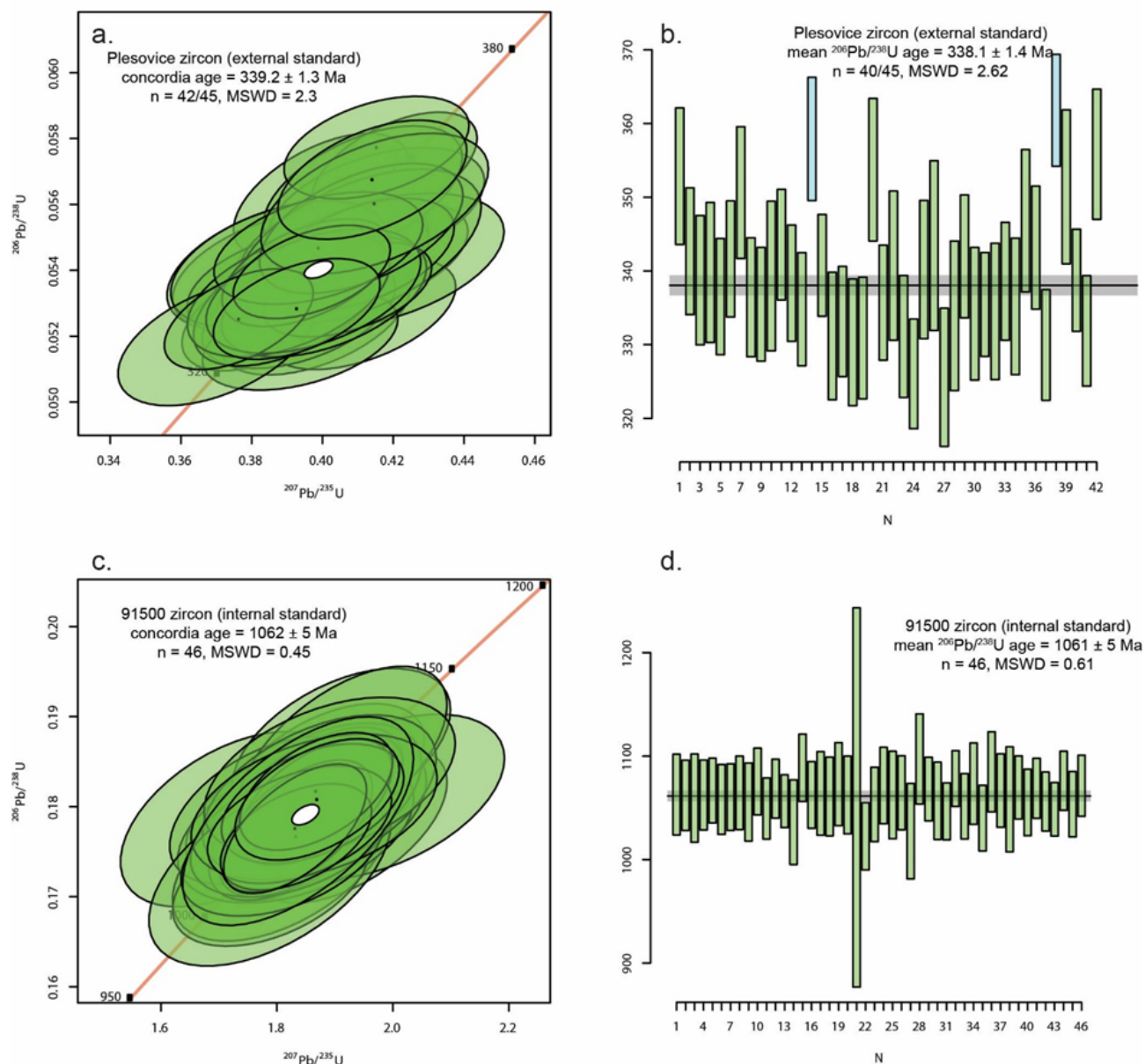
## ANALYTICAL METHODS

### ZIRCON U-PB ANALYSIS VIA LASER ABLATION INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY

Analytical work was carried out at the Analysis Centre in the Shandong Bureau of China Metallurgical Geology Bureau using a Thermo X series 2 ICP-MS equipped with a Geolas Pro 193 nm laser ablation system. For the ablation system, analyses were carried out with a spot diameter of 30 µm and erosion depth of 20–40 µm, with He as the carrier gas and a 10 Hz repetition rate. For the ICP-MS system, analyses were adapted to use low-resolution mode and used NIST610 for instrument signal tuning. The signals for La and Th are more than 30 W, and production rate controlled by monitoring ThO<sup>+</sup>/Th<sup>+</sup> is less than <0.1%, and <sup>238</sup>U/<sup>232</sup>Th closely approximating 1. The data for single-sample analytical spot includes 20 s blank signal and 50 s sample signal. Isotope ratios and element concentration calculations were made using the in-house ICPMSDATA CAL program (by Y Liu). For each 10 sample analytical spots, an internal standard zircon 91500 (c. 1065 Ma; Wiedenbeck et al., 1995) and quality monitoring (external standard) zircon Plesovice (337 ± 0.37 Ma; Sláma et al., 2008) were analysed. Analysis of the Plesovice external standard yielded <sup>206</sup>Pb/<sup>238</sup>U ages within uncertainty of the reference age when considered over the duration of the analytical program, with a weighted mean age of 338.1 ± 1.4 Ma (Fig. 2a, b). Likewise, zircon 91500 yielded the correct values for calibration as an internal standard (Fig. 2c, d).



Description of the zircon morphologies under cathodoluminescence is based on terminology of Corfu et al. (2003). Concordia and weighted mean age diagrams were constructed using IsoplotR (Vermeesch, 2018). Concordia ellipses are constructed at a 95% confidence level, individual age calculations are quoted at  $1\sigma$ , and weighted mean ages are quoted at 95% confidence level. All U-Pb data are in provided in Appendix 1 and are available via SARIG <https://map.sarig.sa.gov.au>.



**Figure 2. Summary of results obtained from standard zircons.** External standard Plesovice (a) Concordia plot, (b) weighted mean  $^{206}\text{Pb}/^{238}\text{U}$  age. Internal standard 91500 (c) Concordia plot, (d) weighted mean  $^{206}\text{Pb}/^{238}\text{U}$  age.

# ZIRCON U-PB LA-ICPMS RESULTS

## BAROSSA COMPLEX

### 3037023, hematite-altered augen gneiss, Houghton Inlier

#### SAMPLE INFORMATION

|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 3037023                                                                         |
| Collector:             | Zhou, Y                                                                         |
| Stratigraphic Unit:    | Barossa Complex                                                                 |
| Location Lat-Long:     | -34.680542 138.847164                                                           |
| Location:              | Northern Houghton Inlier                                                        |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1629 ± 17 Ma                                                                    |
| Age type:              | Metamorphic crystallisation age                                                 |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

#### BACKGROUND

The Barossa Complex is the Proterozoic basement to the Adelaide Rift Complex and forms the southeastern-most exposure of pre-Neoproterozoic crust in Australia. The Barossa Complex comprises a range of metasedimentary and meta-igneous gneisses, including calcsilicate, quartzofeldspathic, psammopelitic, and pelitic gneisses (Meaney, 2017). Deposition of the metasedimentary protoliths to the Barossa Complex occurred between 1730–1655 Ma, synchronous to the onset of the Kimban Orogeny in the Gawler Craton and the deposition of the Willyama Supergroup in the Curnamona Province (Jagodziniski et al., 2020; Meaney, 2017).

Metamorphism initiated in the Barossa Complex at c. 1630 Ma with the development of a low angle metamorphic fabric (Meaney, 2017) and early metamorphic zircon growth recorded in samples from the Houghton Inlier (Belousova et al., 2006). Peak granulite conditions of approximately 8–9 kbar and 800–850 °C occurred at c. 1590 Ma in the southern Barossa Complex (Szpunar et al., 2007; Morrissey et al., 2013).

The set of samples in this report from the Barossa Complex are from the northern Houghton Inlier. Sample 3037023 is an augen gneiss (Fig. 3).



**Figure 3. Photographs of sample 3037023. (a) Field setting. (b) Cut surface of sample 3037023.**

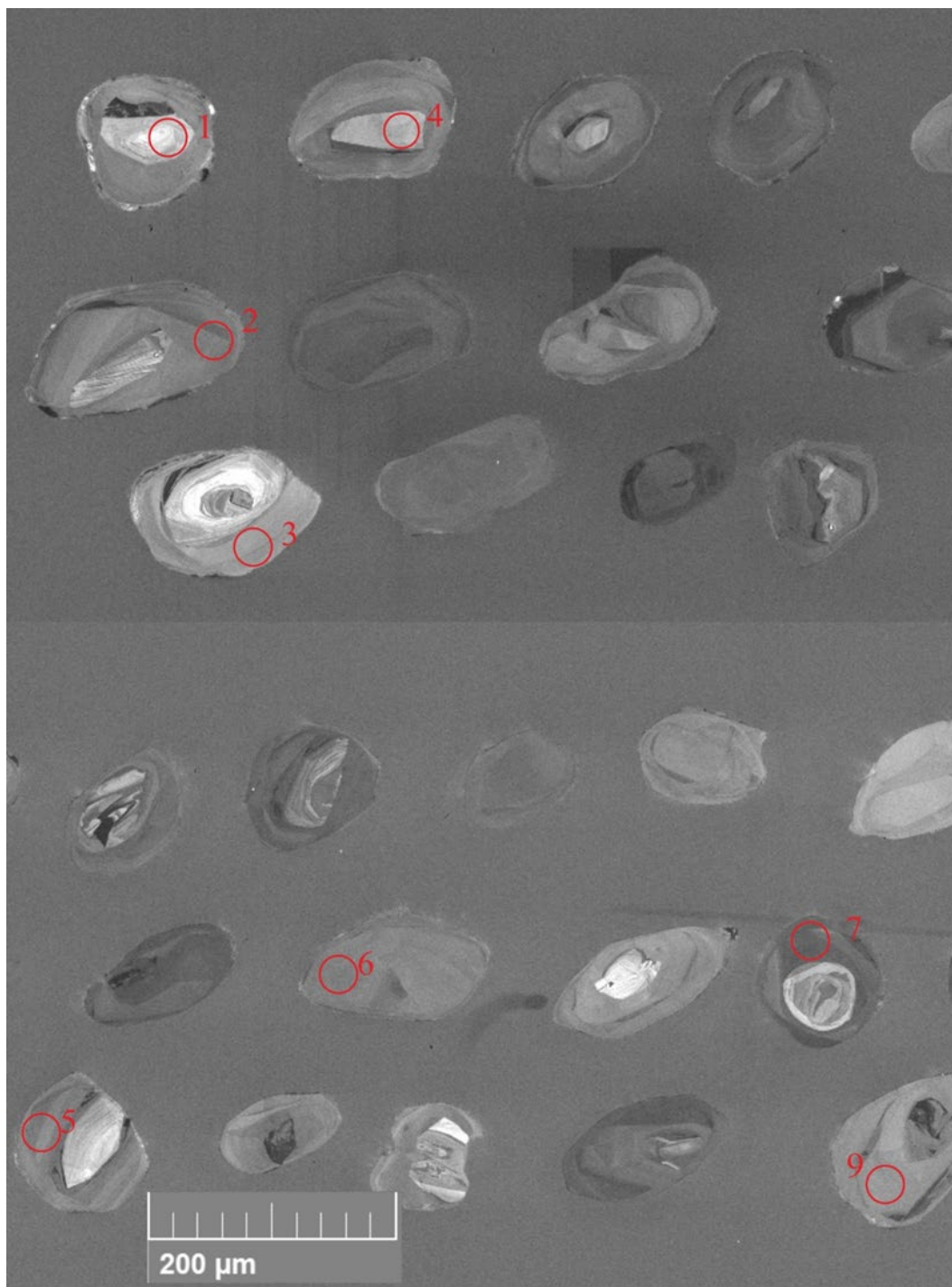


## PETROGRAPHY

Not available for this sample.

## ZIRCON CHARACTERISTICS

Zircons from this sample are generally rounded in shape and under CL are two phase, with bright CL response core domains and darker CL response rims (Fig. 4). The core domains have some zonation, in some examples appearing to be oscillatory in others more broad zonation. The rim domains dominate the zircons and are broad to sector zoned, and have the appearance of metamorphic zircon. While the zonation in some internal cores appear to be truncated by the darker CL response rims, others have more concordant layering in them that could be ghost zonation and suggestive of recrystallisation of the zircon during metamorphism.

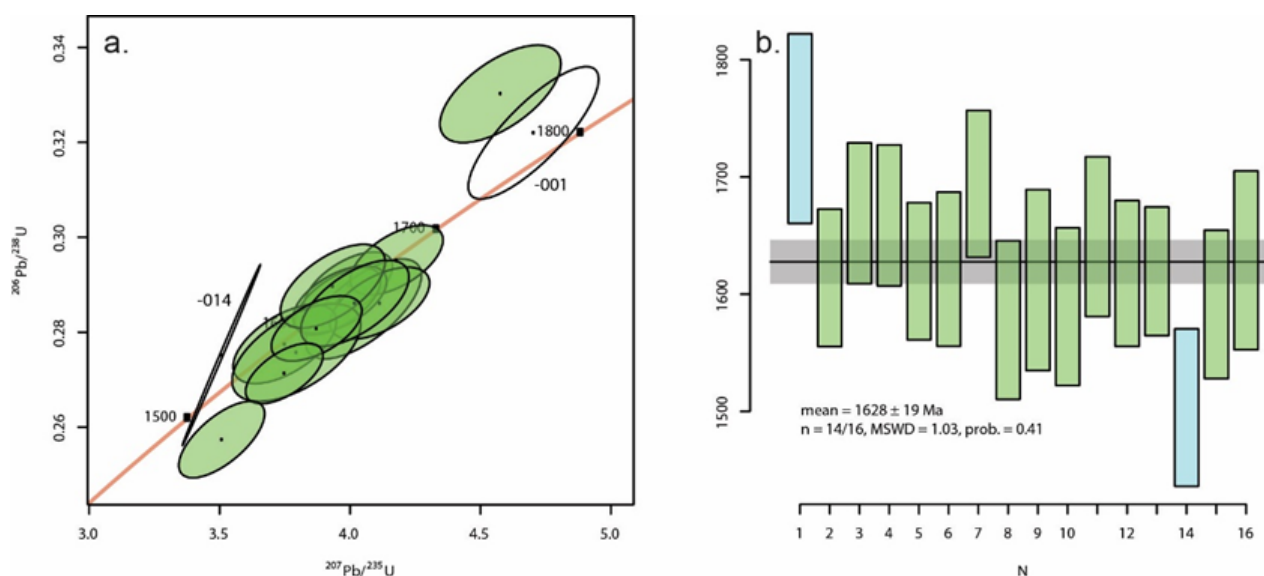


**Figure 4. Representative CL image of zircons from sample 3037023.** Circles indicate analytical sites.

## GEOCHRONOLOGICAL RESULTS

Sixteen zircons were analysed from sample 3037023 (Fig. 5). The majority of the analyses targeted the rim domains as the core domains were too small for analysis using the laser ablation system. Overall the data are concordant or near concordant and cluster at around c. 1630 Ma. Analysis -001 targeted a light CL core domain and has an age of  $1743 \pm 42$  Ma, which does not fall into the c. 1630 Ma cluster. Analysis -004, which also targeted a core domain, has an age of  $1669 \pm 30$  Ma. Analysis -015 has a younger age of  $1503 \pm 35$  Ma and is an outlier to the main population. This analysis is from a light CL response grain. A weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1629 \pm 17$  Ma ( $n = 14$ , MSWD = 0.98, prob. = 0.47) can be calculated from the main group of analyses (Fig. 5b).

Based on the morphology of the zircons,  $1629 \pm 17$  Ma is interpreted to record the timing of metamorphic crystallisation of zircon in this sample.



**Figure 5. Geochronology results for sample 3037023. (a) Concordia diagram. (b) Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation for the main cluster of analyses.**

## 3037022, augen gneiss, Houghton Inlier

### SAMPLE INFORMATION

|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 3037022                                                                         |
| Collector:             | Zhou, Y                                                                         |
| Stratigraphic Unit:    | Barossa Complex                                                                 |
| Location Lat-Long:     | -34.680542 138.847164                                                           |
| Location:              | Northern Houghton Inlier                                                        |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1709 ± 25 Ma                                                                    |
| Age type:              | Magmatic crystallisation age                                                    |
| Interpreted age:       | 1638 ± 10 Ma                                                                    |
| Age type:              | Metamorphic crystallisation age                                                 |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

### BACKGROUND

Sample 3037022 is of the augen granite gneiss in the northern Houghton Inlier (Fig. 6).

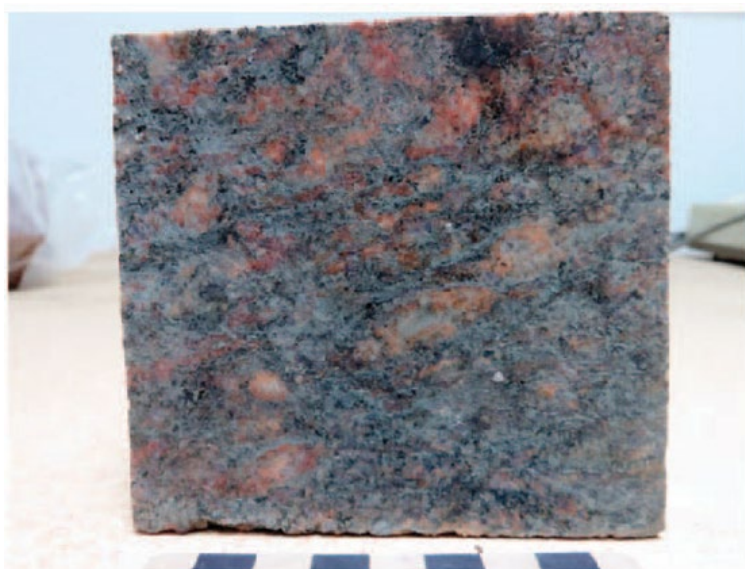


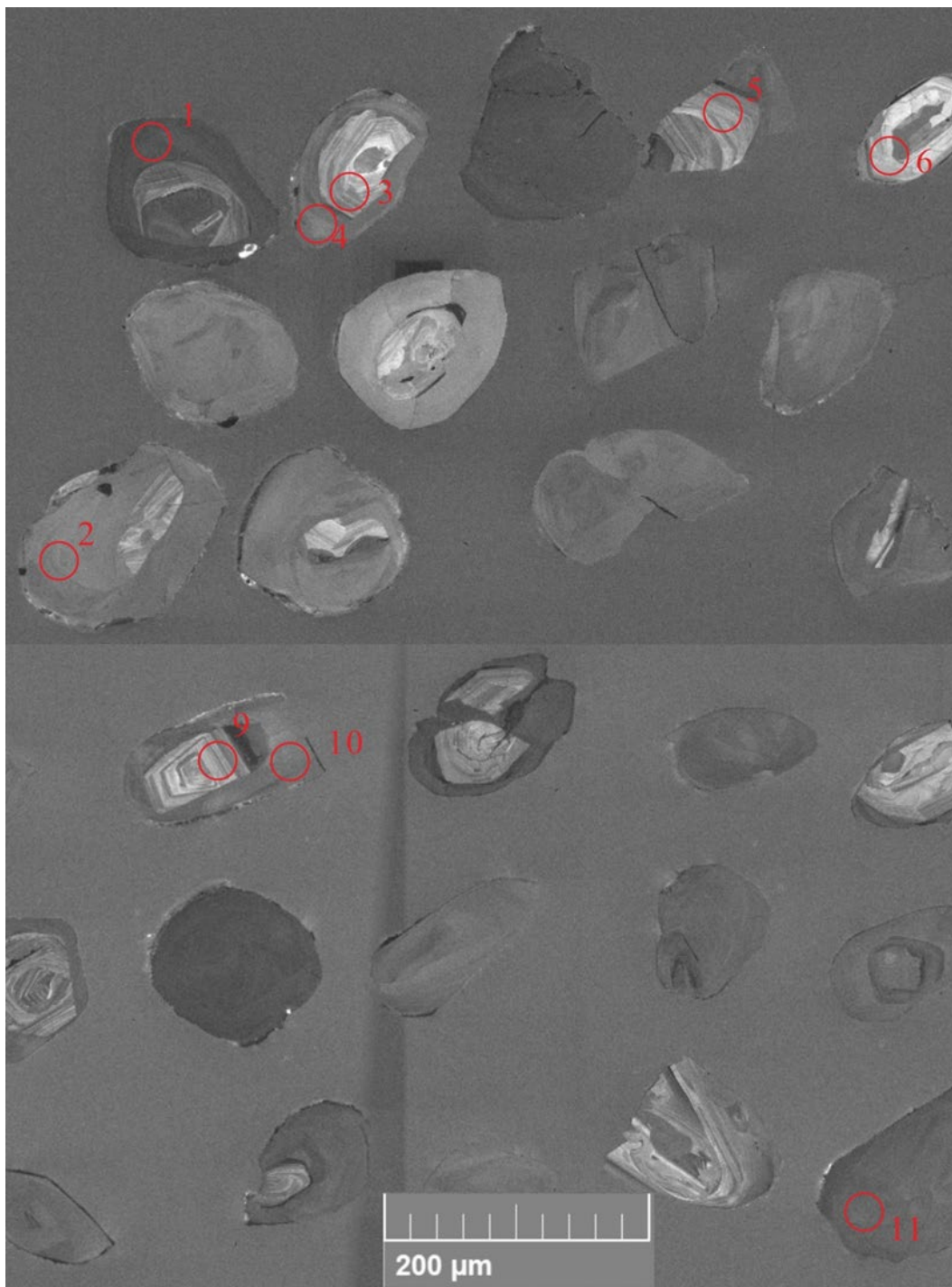
Figure 6. Photograph of cut surface of sample 3037022.

### PETROGRAPHY

Not available for this sample.

### ZIRCON CHARACTERISTICS

Zircons from this sample are generally rounded or have a low width to length ratio. Under CL the zircons have two phases, with bright CL response core domains and darker CL response rims (Fig. 7). The core domains have some zonation, in some examples appearing to be oscillatory in others more broad zonation. The rim domains are broad to sector zoned, and have the appearance of metamorphic zircon. While the zonation in some internal cores appear to be truncated by the darker CL response rims, others have more concordant layering in them that could be ghost zonation and suggestive of recrystallisation of the zircon during metamorphism.



**Figure 7. Representative CL image of zircons from sample 3037022.** Circles indicate analytical sites.

## GEOCHRONOLOGICAL RESULTS

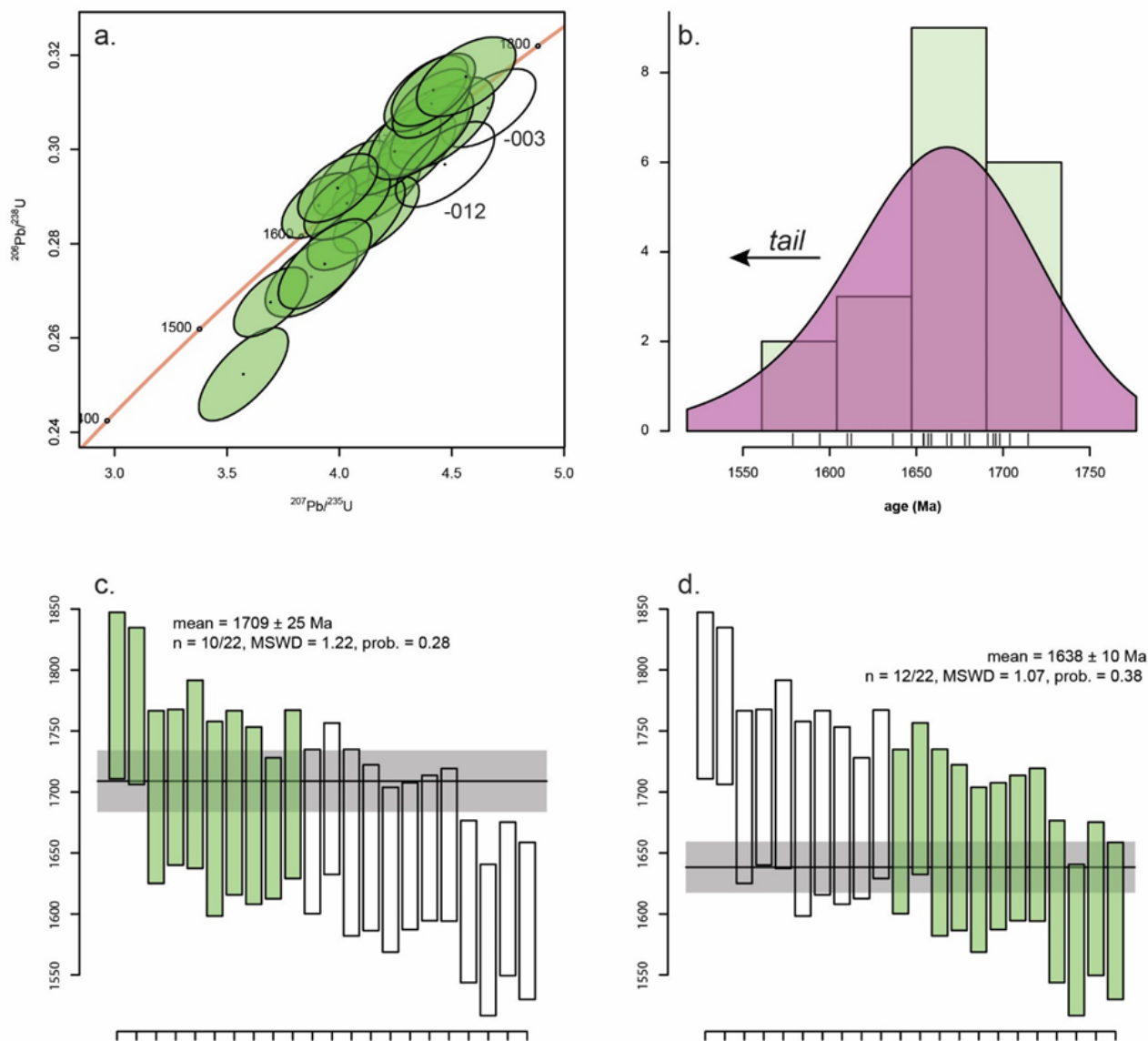
Twenty two zircons were analysed from sample 3037022. The majority are concordant or near concordant (Fig. 8a). The data appear to cluster at around c. 1630 Ma, with two older analyses that are outliers to this populations. Analyses -003 and -012 have ages of  $1772 \pm 32$  Ma and  $1780 \pm 34$  Ma respectively and derive from light CL core domains. The remaining analyses range from c. 1716 Ma to c. 1589 Ma. A kernal density distribution for the data set is suggestive of asymmetry in the distribution, with ages on the younger end forming a 'tail' in the distribution (Fig. 8b).

This is consistent with a grouping on the basis of zircon morphology, such that zircon core domains have ages that range from  $1780 \pm 34$  Ma to  $1699 \pm 68$  Ma, while the rim analyses range in age from  $1678 \pm 33$  Ma to  $1595 \pm 33$  Ma.



Grouping the core analyses yields a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1709 \pm 25$  Ma (Fig. 8c;  $n = 10/22$ , MSWD = 1.22, prob. = 0.28), which suggests the cores represent a single population of zircon, consistent with an igneous precursor to the augen gneiss. The age  $1709 \pm 25$  Ma is therefore considered the emplacement age of the granite.

Grouping the rim analyses yields a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1638 \pm 10$  Ma (Fig. 8d;  $n = 12/22$ , MSWD = 1.07, prob. = 0.38). This age is interpreted to reflect the timing of metamorphic recrystallisation of zircon in the sample.



**Figure 8. Geochronology results for sample 3037022. (a)** Concordia diagram. Outliers of analyses -003 and -012 are not coloured. **(b)** Kernel density distribution for all analyses. **(c)** Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation for zircon core analyses. **(d)** Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation for zircon rim analyses.

## 3037021, augen gneiss, Houghton Inlier

### SAMPLE INFORMATION

|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 3037021                                                                         |
| Collector:             | Zhou, Y                                                                         |
| Stratigraphic Unit:    | Barossa Complex                                                                 |
| Location Lat-Long:     | -34.680542 138.847164                                                           |
| Location:              | Northern Houghton Inlier                                                        |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1678 ± 30 Ma                                                                    |
| Age type:              | Magmatic crystallisation age                                                    |
| Interpreted age:       | 1650 ± 23 Ma                                                                    |
| Age type:              | Metamorphic crystallisation age                                                 |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

### BACKGROUND

Sample 3037022 is of augen gneiss in the northern Houghton Inlier (Fig. 9).

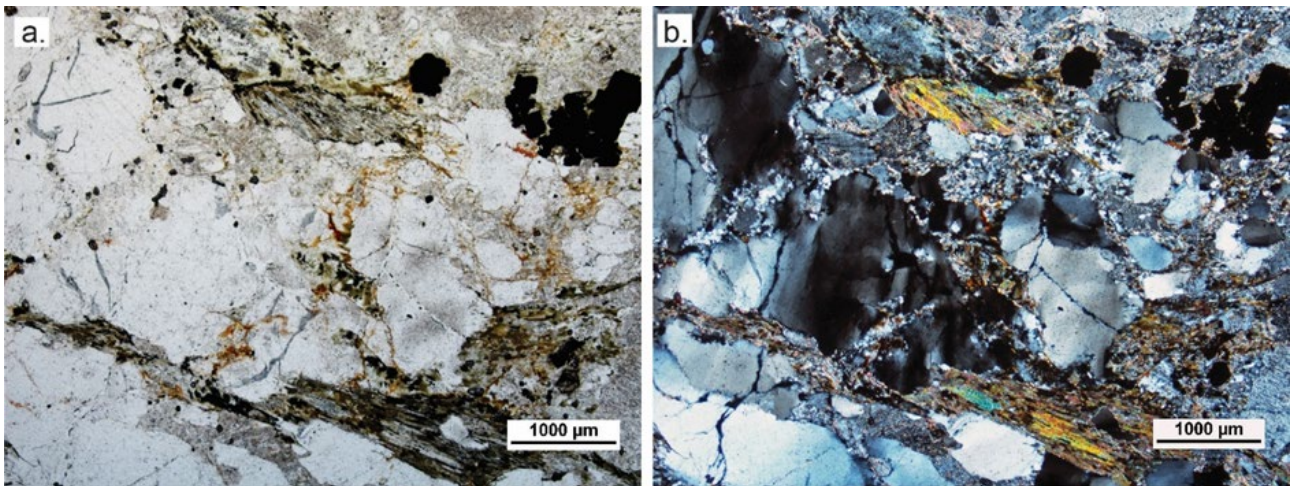


Figure 9. Photograph of sample 3037021.

### PETROGRAPHY

Sample 3037021 is a medium-grained granite that has undergone deformation and moderate hydrothermal alteration. The granite comprises quartz, plagioclase and lesser K-feldspar and has a weak planar mineral alignment that is partly defined by broad alignment of ragged and altered muscovite (Fig. 10). The quartz is partly dynamically recrystallised into both smaller sub-grains and also larger relict igneous grains that have extensive undulose extinction. The plagioclase is mostly altered to sericite and is poorly preserved in this sample. K-feldspar is a minor phase and also partly altered to sericite. Muscovite appears to have been an igneous phase and is partly or wholly altered being replaced by clots of sericite and/or chlorite. Opaque phases within the sample are likely magnetite or an iron rich phase after magnetite. Clays and hematite staining are prevalent throughout the sample and micro-fractures cut across the mineral foliation.

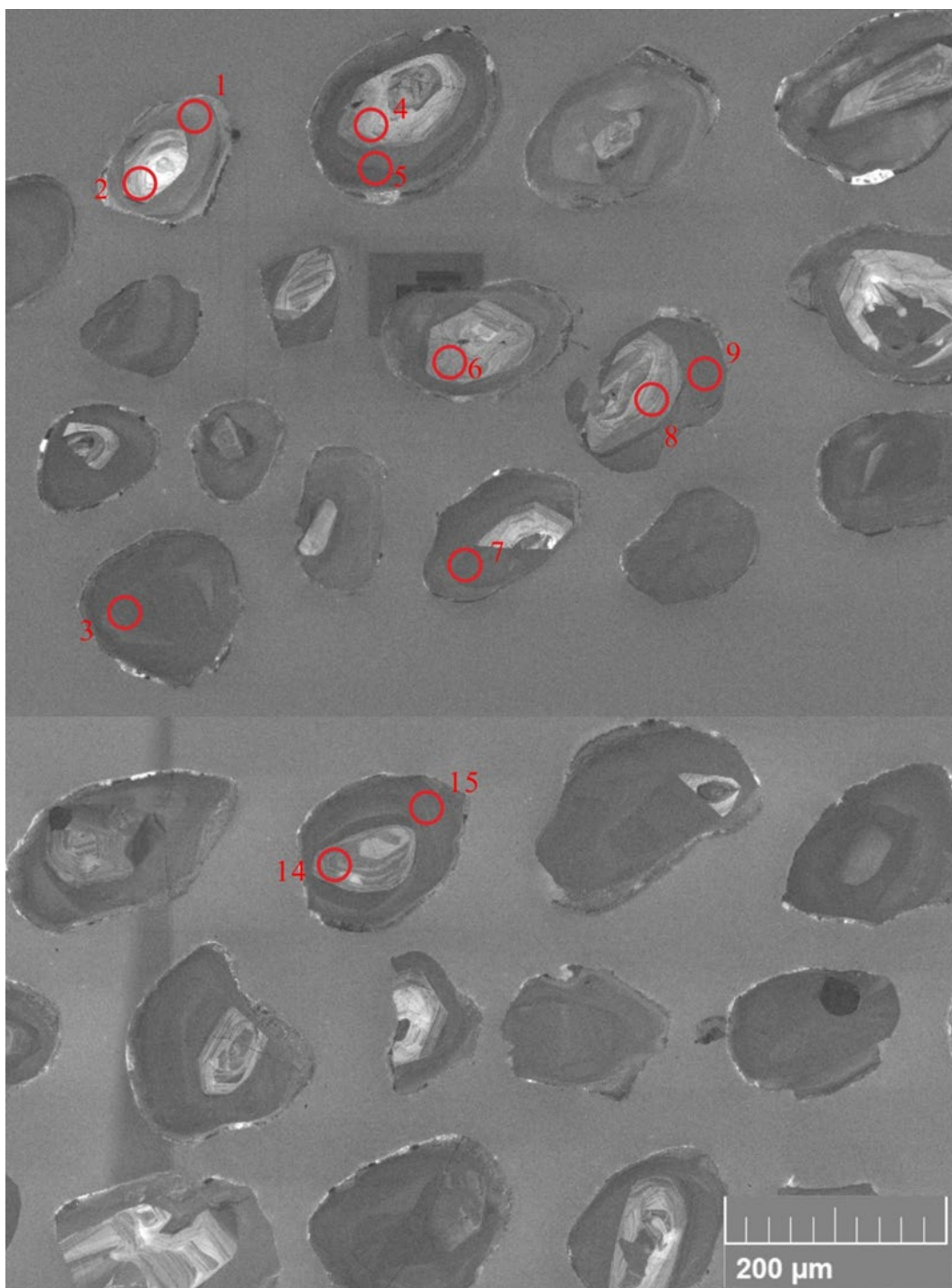




**Figure 10. Photomicrographs of sample 3037021. (a) Transmitted plane polarised light. (b) Cross polars.**

### **ZIRCON CHARACTERISTICS**

Zircons from this sample are generally rounded or have a low width to length ratio. Under CL the zircons have two phases, with bright CL response core domains and darker CL response rims (Fig. 11). The core domains have some zonation, in some examples appearing to be oscillatory in others more broad zonation. The rim domains are broad to sector zoned, and have the appearance of metamorphic zircon. While the zonation in some internal cores appear to be truncated by the darker CL response rims, others have more concordant layering in them that could be ghost zonation and suggestive of recrystallisation of the zircon during metamorphism.



**Figure 11. Representative CL image of zircons from sample 3037021.** Circles indicate analytical sites.

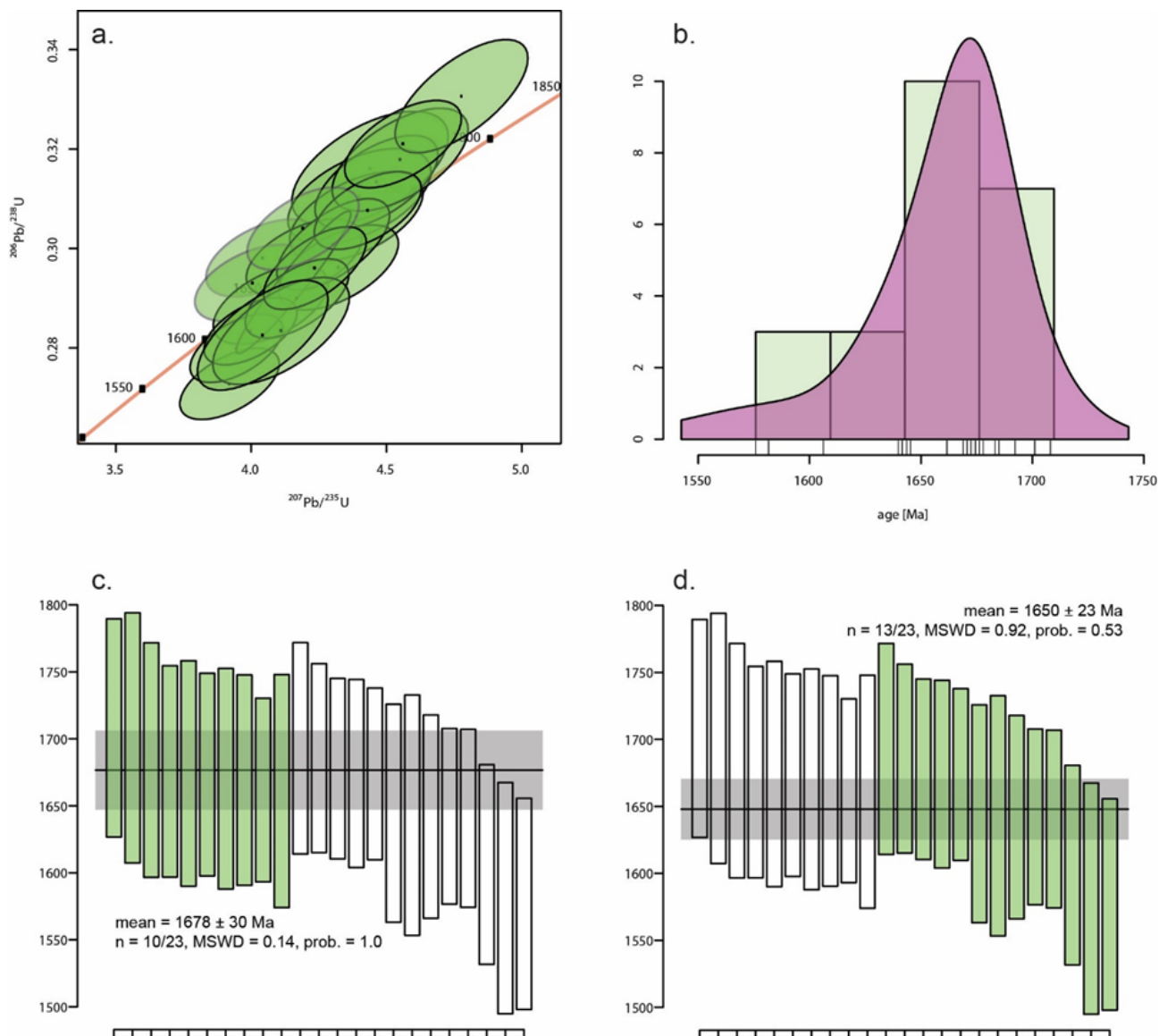
## GEOCHRONOLOGICAL RESULTS

Twenty three analyses were made on zircons from sample 3037021 and the data are concordant or near concordant and range from c. 1700 to c. 1600 Ma (Fig. 12a, b). The analyses are from both core and rim domains.

The core domains have ages that range from  $1709 \pm 36$  Ma and  $1662 \pm 44$  Ma. Combining all the analyses of core domains produces a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1678 \pm 30$  Ma (Fig. 12c;  $n = 10/23$ , MSWD = 0.14, prob. = 1.0).

The rim domains have ages that range from  $1694 \pm 73$  Ma to  $1578 \pm 40$  Ma. Combining all the analyses of rim domains produces a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of mean =  $1650 \pm 23$  Ma (Fig. 12d;  $n = 13/23$ , MSWD = 0.92, prob. = 0.53).

The  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for core and rim domains from this sample are not as differentiated compared to ages from the previous two samples of the augen gneiss from the Houghton Inlier. This could be a result of smaller rim domains in the zircons for this sample and the laser ablation analysis incorporating both core and rim into the analyses. In addition, the similarity in age between the core and rim domain analyses could reflect partial isotopic resetting during the metamorphic event leading to a smear of analyses along concordia. This would result in ages that are between the true magmatic and metamorphic crystallisation ages. The  $1678 \pm 30$  Ma age is interpreted to be an estimate of the timing of crystallisation of zircon in the sample. The  $1650 \pm 23$  Ma age could be an estimate of the timing of metamorphic recrystallisation in the sample, however, this is not considered as robust an estimate of timing for this event in comparison to the previous samples.



**Figure 12. Geochronology results for sample 3037021. (a)** Concordia diagram. Outliers are not coloured. **(b)** Kernel density distribution. **(c)** Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation for core analyses. **(d)** Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation for rim analyses.



## PALEOPROTEROZOIC ROCKS OF YORKE PENINSULA

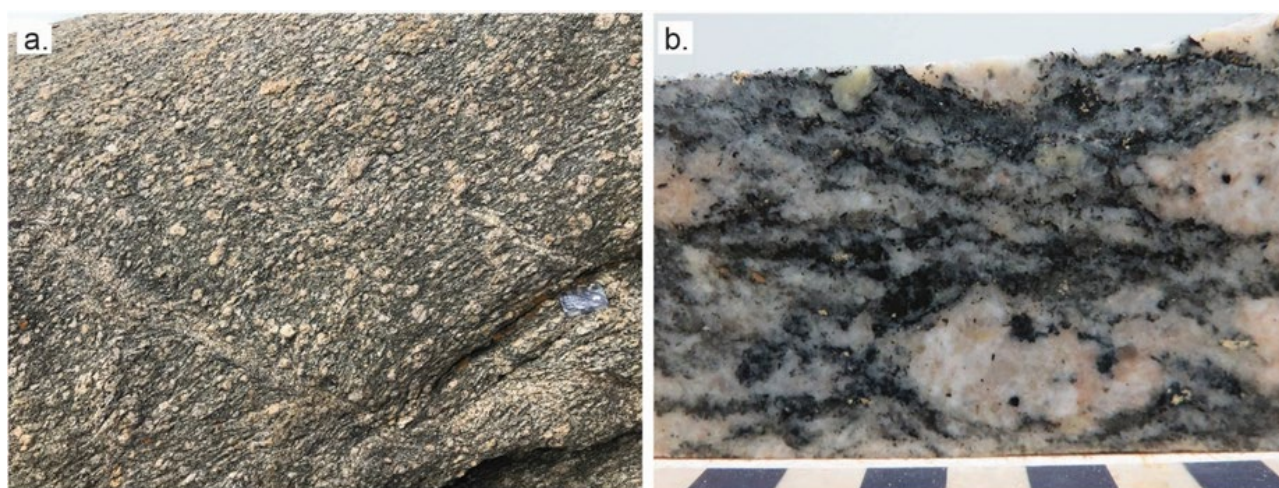
### 3037029, augen gneiss, Berry Bay

#### SAMPLE INFORMATION

|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 3037029                                                                         |
| Collector:             | Zhao, Y                                                                         |
| Stratigraphic Unit:    | Gleesons Landing Granite, Donington Suite                                       |
| Location Lat-Long:     | -34.921      137.0114                                                           |
| Location:              | Berry Bay, Yorke Peninsula                                                      |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1834 ± 18 Ma                                                                    |
| Age type:              | Magmatic crystallisation age                                                    |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

#### BACKGROUND

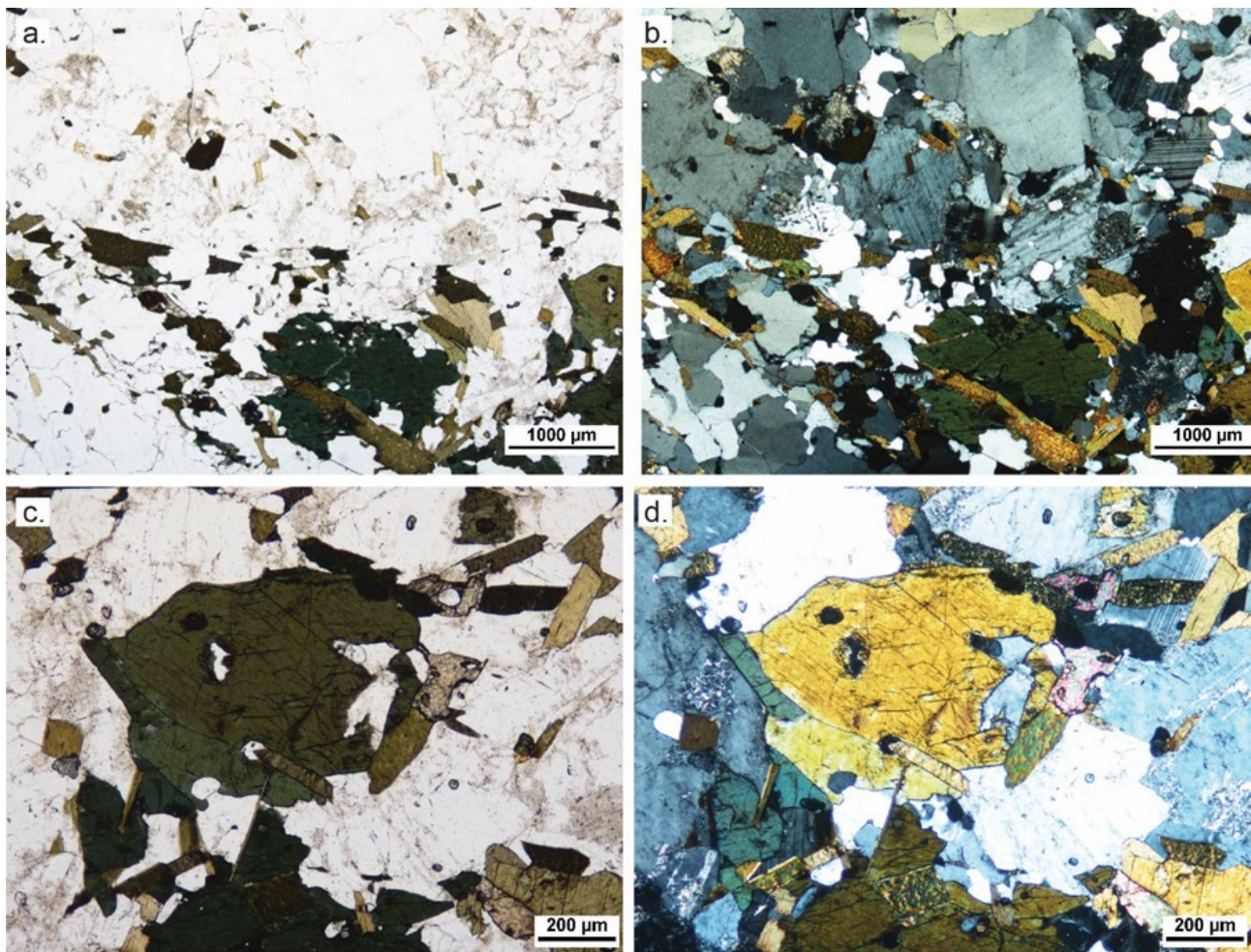
This sample is an augen gneiss from Berry Bay southern Yorke Peninsula part of the Gleesons Landing Granite of the Donington Suite (Fig. 13). The sample is a megacrystic granite with coarse K-feldspar and a foliation defined by biotite, hornblende and quartz-feldspar (plagioclase and K-feldspar). The rock is weakly altered with some clays replacing biotite and or chlorite.



**Figure 13. Field photograph of augen gneiss of the Gleesons Landing Granite. (a)** Field photo at Berry Bay, Yorke Peninsula. **(b)** Sample 3037029.

#### PETROGRAPHY

Sample 3037029 is a foliated hornblende-biotite bearing granite. The quartz and feldspar (dominantly plagioclase) is extensively recrystallised (Fig. 14a, b). Sub-grain development, irregular grain boundaries and undulose extinction is common in the quartz. Plagioclase is intergrown with the quartz and weakly altered to sericite. Larger K-feldspar grains 2 to 4mm wide occur within the sample and have fringes of dynamically recrystallised quartz surrounding them, forming augen texture. The main foliation is defined by alignment of biotite and hornblende, although some of the larger quartz grains are also broadly aligned with the micas (Fig. 14c, d). There is also titanite in the sample. This is a metamorphosed granodiorite.

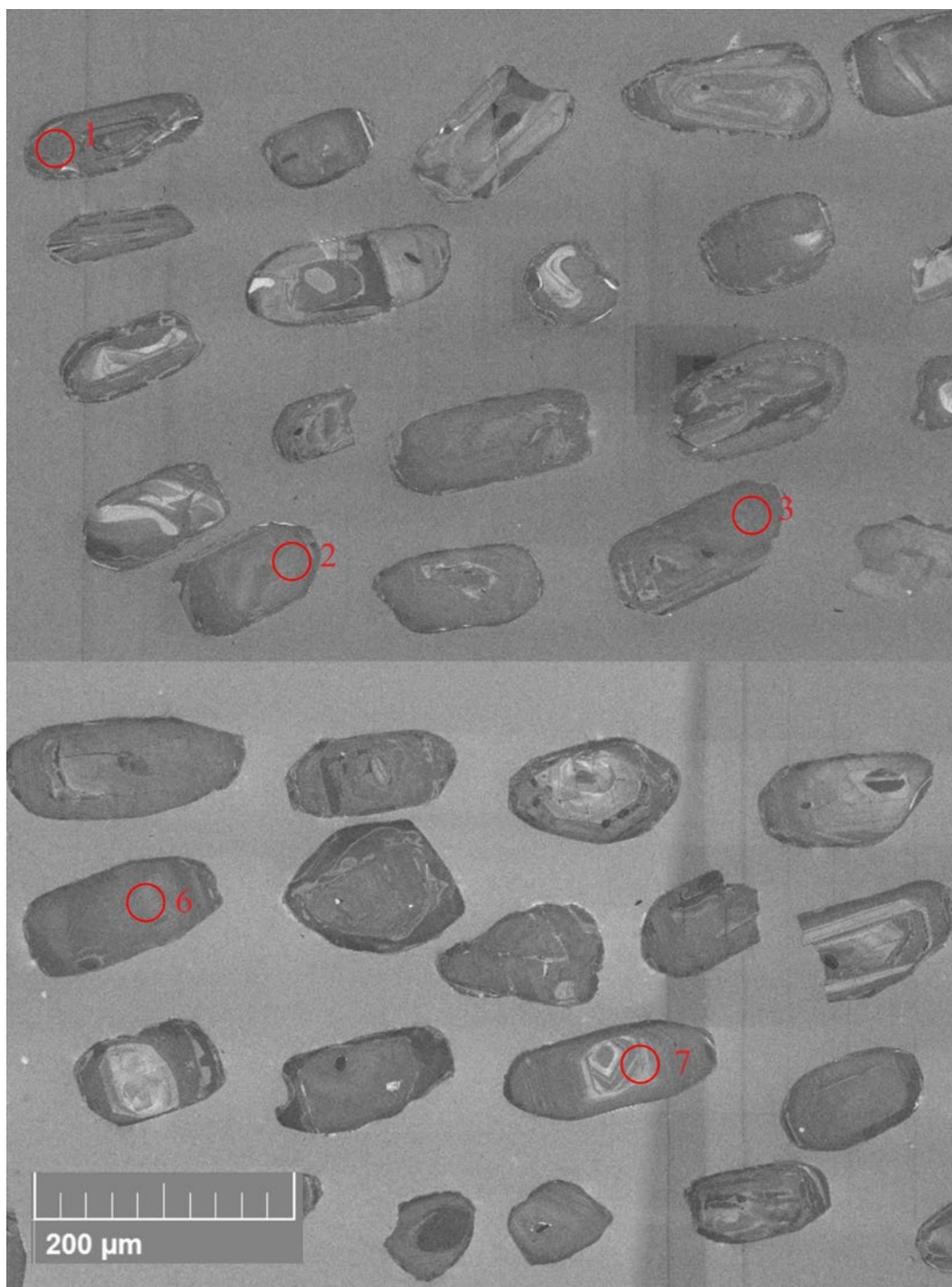


**Figure 14. Photomicrographs of sample 3037029. (a)** Transmitted plane polarised light. **(b)** Cross polars. **(c)** Detail of hornblende-biotite-titanite from sample 3037029, transmitted light. **(d)** Cross polars.

## ZIRCON CHARACTERISTICS

Zircons from this sample have length to width ratios around 2:1 to 3:1, although some grains are more equant in morphology (Fig. 15). Some grains have irregular and distorted zonation patterns suggesting they are metamict. However, many grains have broadly oscillatory zonation typical of igneous zircon. The presence of lighter CL response cores with light grey to black rims in some grains could suggest the presence of inherited cores. However, the concordance of the zonation between the internal and external zones, despite the variation in CL response suggests these are likely to be magmatic features.

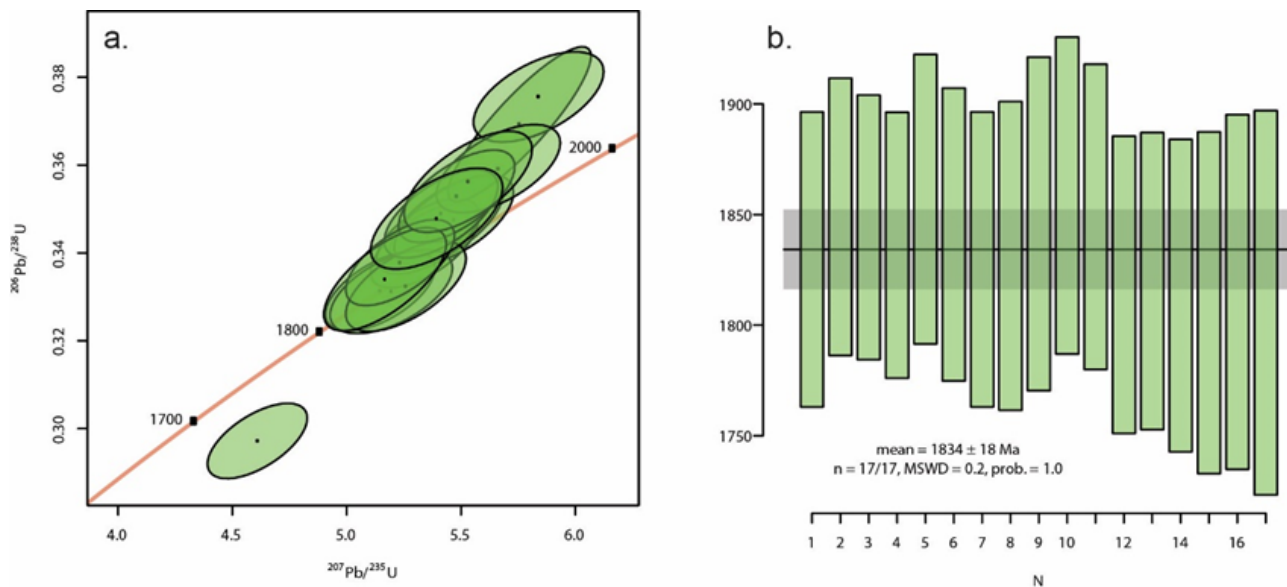




**Figure 15. Representative CL image of zircons from sample 3037029. Circles indicate analytical sites.**

## GEOCHRONOLOGICAL RESULTS

Seventeen zircons were analysed from this sample. All produced concordant or near concordant analyses and can be pooled to yield a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1834 \pm 18$  Ma (Fig. 16). This age is interpreted to be the timing of magmatic crystallisation of the sample. This age is within uncertainty of other zircon crystallisation ages for the Donington Suite (Jagodzinski et al., 2006; Reid et al., 2008).



**Figure 16. Geochronology results for sample 3037029. (a) Concordia diagram. (b) Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation.**

## 3037025, rhyodacite, Port Victoria

### SAMPLE INFORMATION

|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 3037025                                                                         |
| Collector:             | Zhou, Y                                                                         |
| Stratigraphic Unit:    | Wardang Volcanics Member, Wallaroo Group                                        |
| Location Lat-Long:     | -34.505      137.4796                                                           |
| Location:              | Port Victoria, Yorke Peninsula                                                  |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1779 ± 31 Ma                                                                    |
| Age type:              | Magmatic crystallisation age                                                    |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

### BACKGROUND

The Wardang Volcanics Member is characterised by rhyodacite to dacite volcanic rocks, with extrusive features, peperite and local contemporaneous sedimentation (Cowley et al., 2003). The sample is rhyodacite in composition and has a fine grained feldspar and quartz groundmass, with plagioclase phenocrysts (Fig. 17).

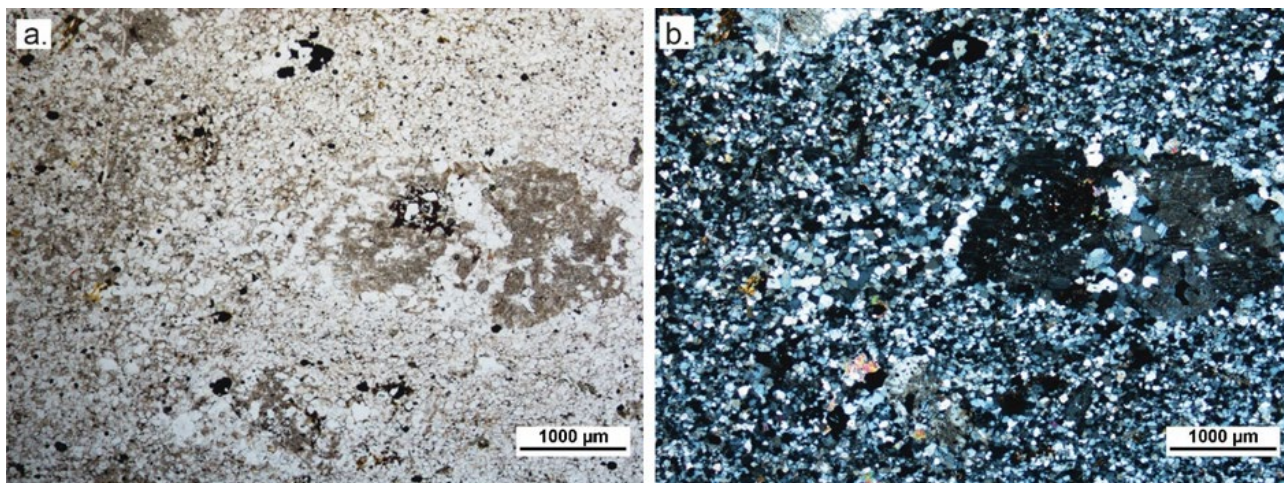


**Figure 17. Photographs of sample 3037025. (a)** Port Victoria coastline with outcrop of Wardang Volcanics Member. **(b)** Photograph of sample 3037025.

### PETROGRAPHY

Sample 3037025 comprises a fine-grained groundmass of quartz and lesser feldspar, occurring as equant grains with no preferred orientation (Fig. 18). Within the groundmass are 1–2mm size clots of altered and recrystallised plagioclase feldspar and quartz. Minor opaque phases are present in the rock and sericite clots are also present in places. The rock has the appearance of a recrystallised felsic volcanic, with the large clots likely being former amygdalae within the volcanic rock.



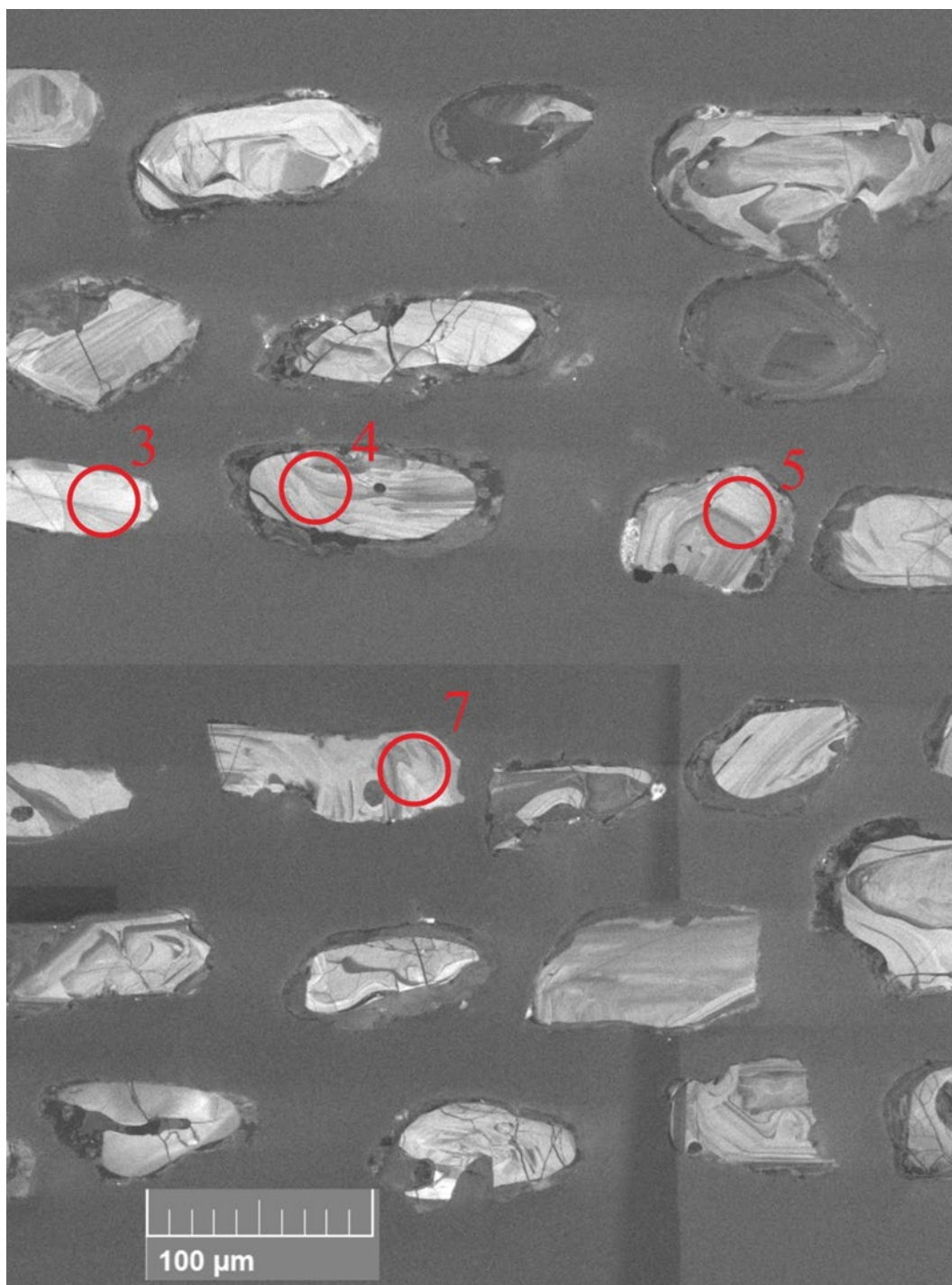


**Figure 18. Photomicrographs of sample 3037025. (a)** Transmitted plane polarised light.  
**(b)** Cross polars.

### **ZIRCON CHARACTERISTICS**

Zircons from this sample comprise internal core domains with light CL response and dominantly oscillatory zonation, and rim domains with dark CL response (Fig. 19). The oscillatory zoned cores are igneous in origin. In some examples, dark zones appear to be inclusions within the zircon, possibly apatite or silicate mineral such as feldspar. One example shows a narrow, tubular structure within the light CL core region that resembles a tubular inclusion trail, a feature typical of volcanic rocks. The rim domains are typically narrow, around 10 µm, and are too small to analyse with the laser ablation system.

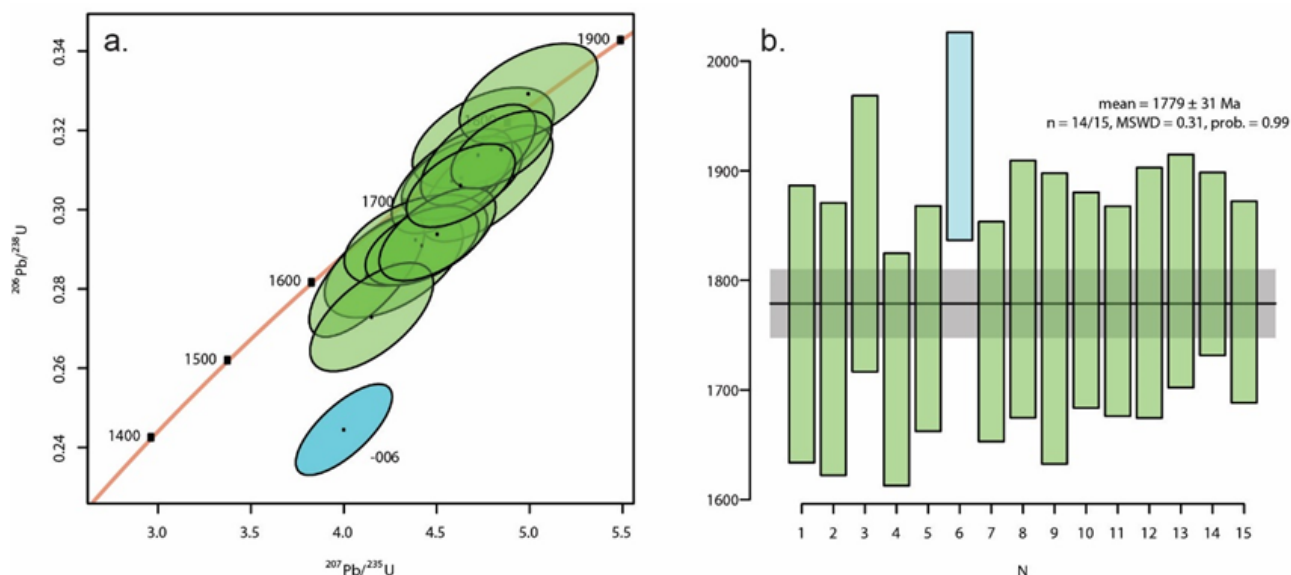




**Figure 19. Representative CL image of zircons from sample 3037025. Circles indicate analytical sites.**

## GEOCHRONOLOGICAL RESULTS

Fifteen analyses were made on zircons from sample 3037025. The data are concordant or near concordant, with the exception of analyses -006, which is 85% concordant (Fig. 20). Analysis -006 is also slightly older than the main cluster of ages, which is likely a function of the relatively high common Pb component (4.76%). Omitting this analysis gives a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1779 \pm 31$  Ma (Fig. 20b;  $n = 14$ ,  $\text{MSWD} = 0.31$ ,  $\text{prob.} = 0.99$ ). This is interpreted to be the timing of crystallisation of the felsic volcanic. This age is within uncertainty of the previous age for the Wardang Volcanics. Fanning et al. (2007) reported an age of  $1772 \pm 14$  Ma for a sample of the felsic volcanics from Wardang Island, Yorke Peninsula.



**Figure 20. Geochronology results for sample 3037025. (a) Concordia diagram. (b) Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation.**

## 3037024, metabasalt, Port Victoria

### SAMPLE INFORMATION

|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 3037024                                                                         |
| Collector:             | Zhou, Y                                                                         |
| Stratigraphic Unit:    | Renowden Metabasalt Member, Wallaroo Group                                      |
| Location Lat-Long:     | -34.505      137.4796                                                           |
| Location:              | Port Victoria, Yorke Peninsula                                                  |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1547 ± 56 Ma                                                                    |
| Age type:              | Metamorphic crystallisation age                                                 |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

### BACKGROUND

The Renowden Metabasalt Member is part of the Wallaroo Group and is exposed along the coastline at Port Victoria. The metabasalt is generally massive although a foliation is evident, being defined by alignment of amphibole (Fig. 21).

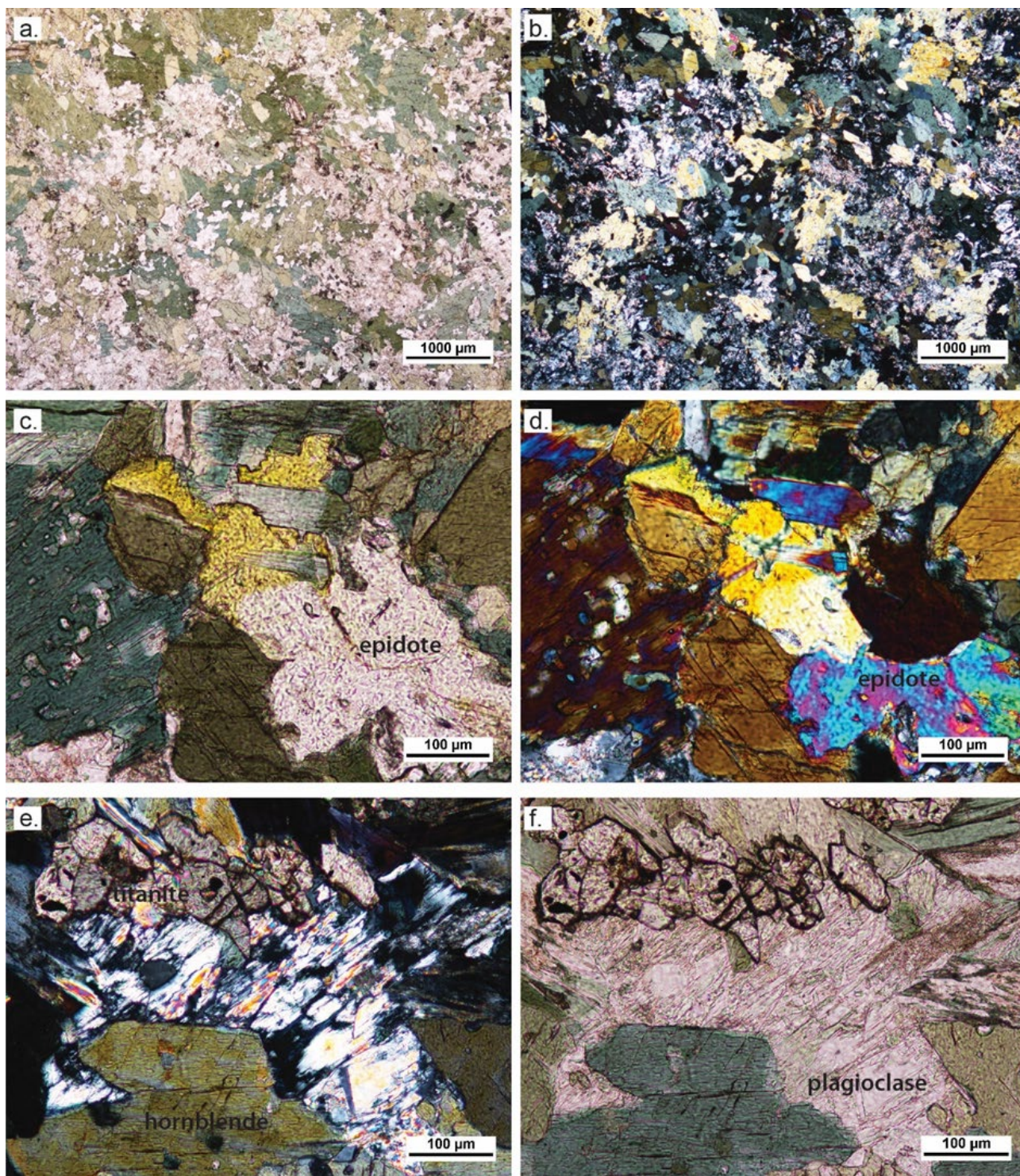


Figure 21. Photograph of sample 3037024.

### PETROGRAPHY

Sample 3037024 consists of a mosaic of amphibole and plagioclase with lesser quartz, titanite, epidote and opaque phases (Fig. 22a, b). The amphibole is hornblende and is in places poikiloblastic with plagioclase inclusions. This suggests possible recrystallisation from a primary pyroxene during metamorphism. There is no preferred orientation in the sample. The plagioclase is partly or wholly sericite altered, and is intergrown with the hornblende and lesser quartz. Epidote occurs as clots and clusters that appear to overprint the amphibole and plagioclase, suggesting it is an alteration feature, rather than part of the metamorphic assemblage (Fig. 22c, d). Titanite to 200  $\mu\text{m}$  long is present in clots associated with hornblende and or altered plagioclase (Fig. 22e, f).



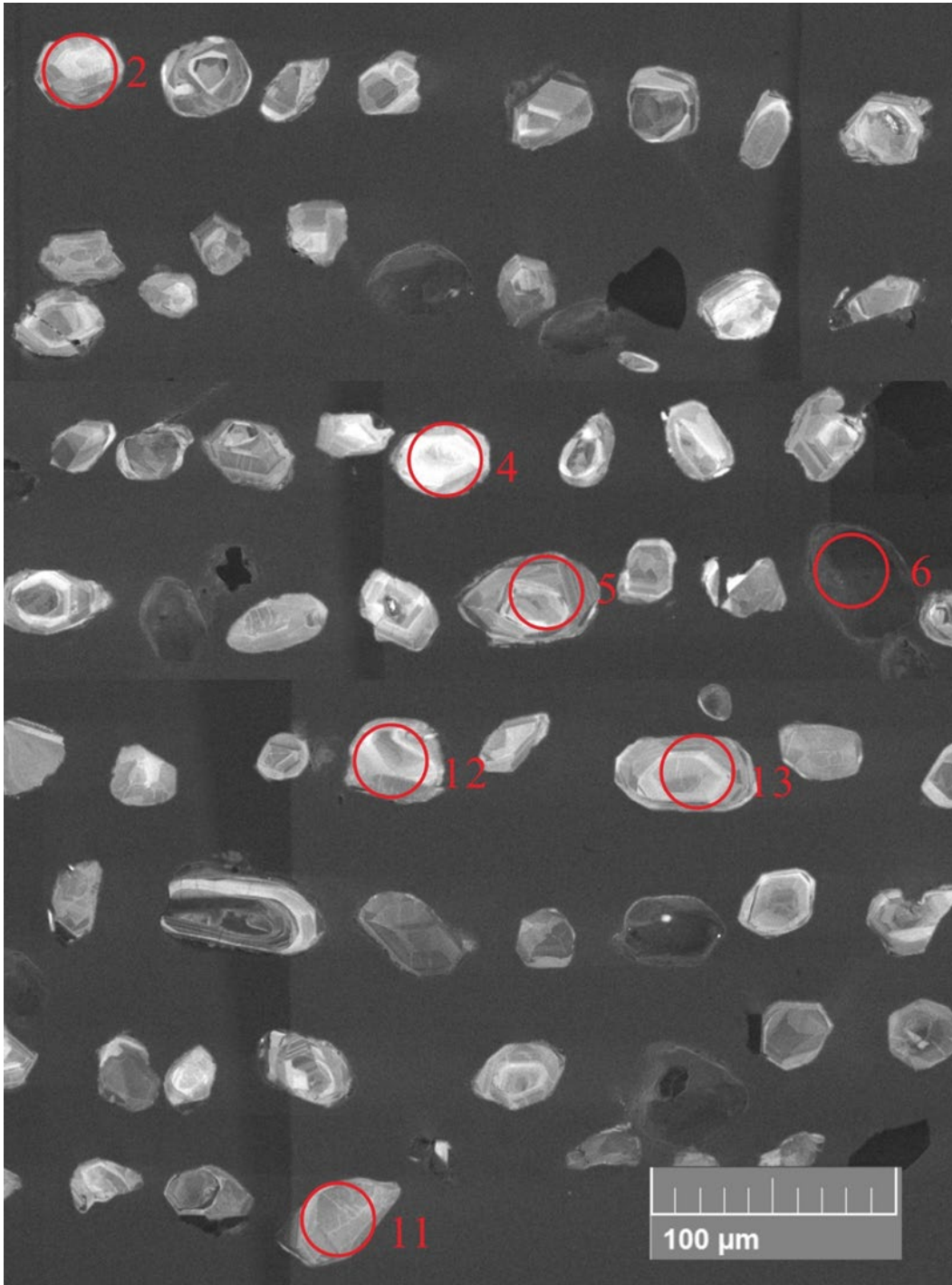


**Figure 22. Photomicrographs of sample 3037024.** (a) Transmitted plane polarised light. (b) Cross polars. (c) Detail of epidote alteration phase in transmitted light. (d) Cross polars. (e) Detail of titanite adjacent plagioclase and hornblende, transmitted light. (f) Cross polars.



## ZIRCON CHARACTERISTICS

Zircons from this sample are squat shaped, with low length to width ratios and generally smaller than 60  $\mu\text{m}$  in length (Fig. 23). The CL response is generally light, and shows broad to sector zonation within the grains. These sector zoned grains could be metamorphic in origin. A few grains appear to have smaller core domains or variable CL response, some with resorbed edges that could represent pre-existing zircon that has undergone metamorphic recrystallisation.

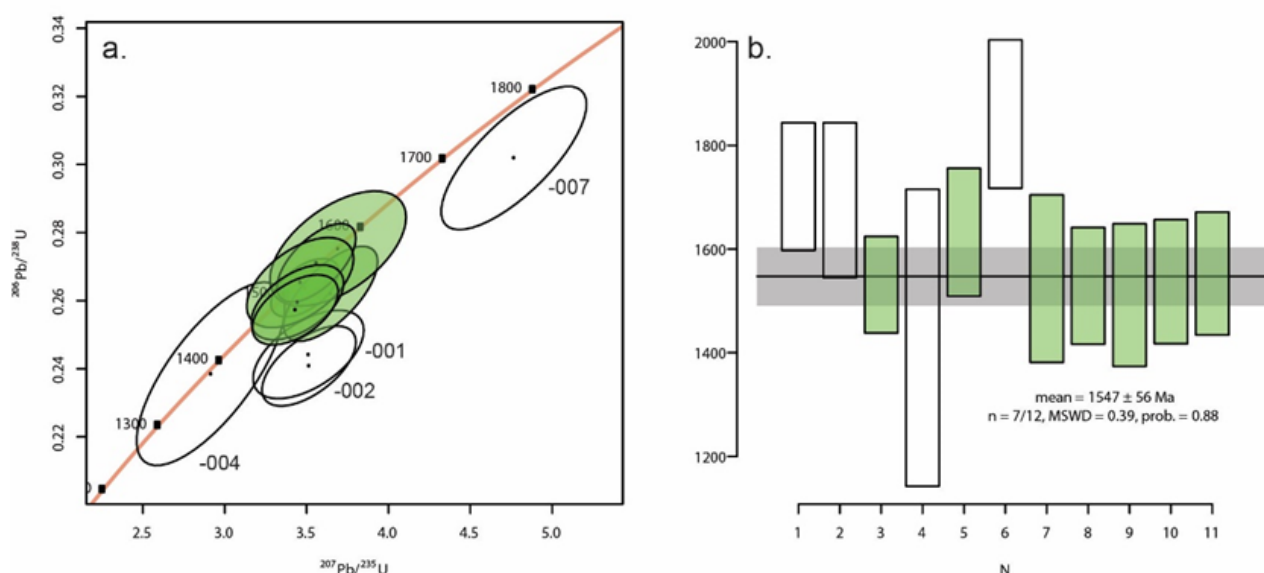


**Figure 23. Representative CL image of zircons from sample 3037024.** Circles indicate analytical sites.

## GEOCHRONOLOGICAL RESULTS

Thirteen zircons were analysed from sample 3037024. Analysis -006 is 71% concordant and has a large uncertainty due to very high common Pb component and is not considered further. There is a single apparently concordant analysis with an age of  $1429 \pm 147$  Ma (analysis -004), however this analysis has a very large uncertainty due to low U and low Pb content and is not considered further. The remaining analyses are near concordant or concordant and the data suggests two main population of zircons (Fig. 24a). There is an older group defined by analyses -001, -002 and -007 which have ages of c. 1721, c. 1695 and c. 1861 Ma. The central group of ages cluster at around c. 1550 Ma and pooling these seven analysis defines a weighted mean age of  $1547 \pm 56$  Ma (Fig. 24b; MSWD = 0.39, prob. = 0.88).

The stratigraphic and outcrop relationships between the Renowden Metabasalt Member and other units of the Wallaroo Group demonstrate this unit is Paleoproterozoic in age. Therefore the simplest interpretation of the age data is that  $1547 \pm 56$  Ma records the timing of metamorphic recrystallisation of zircon. Potentially this is linked to redistribution of zirconia and silica during metamorphism, likely during the cooling or post-peak phase of the metamorphic cycle (e.g. Kohn et al., 2015). The presence of older zircon with ages between c.1695 Ma and 1861 Ma are interpreted to be inherited.



**Figure 24. Geochronology results for sample 3037024. (a)** Concordia diagram highlighting outliers in blue and grey. **(b)** Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation for main cluster of analyses.

## 2665664, microgranite, drillhole CUR D5, 78.5–78.9 m

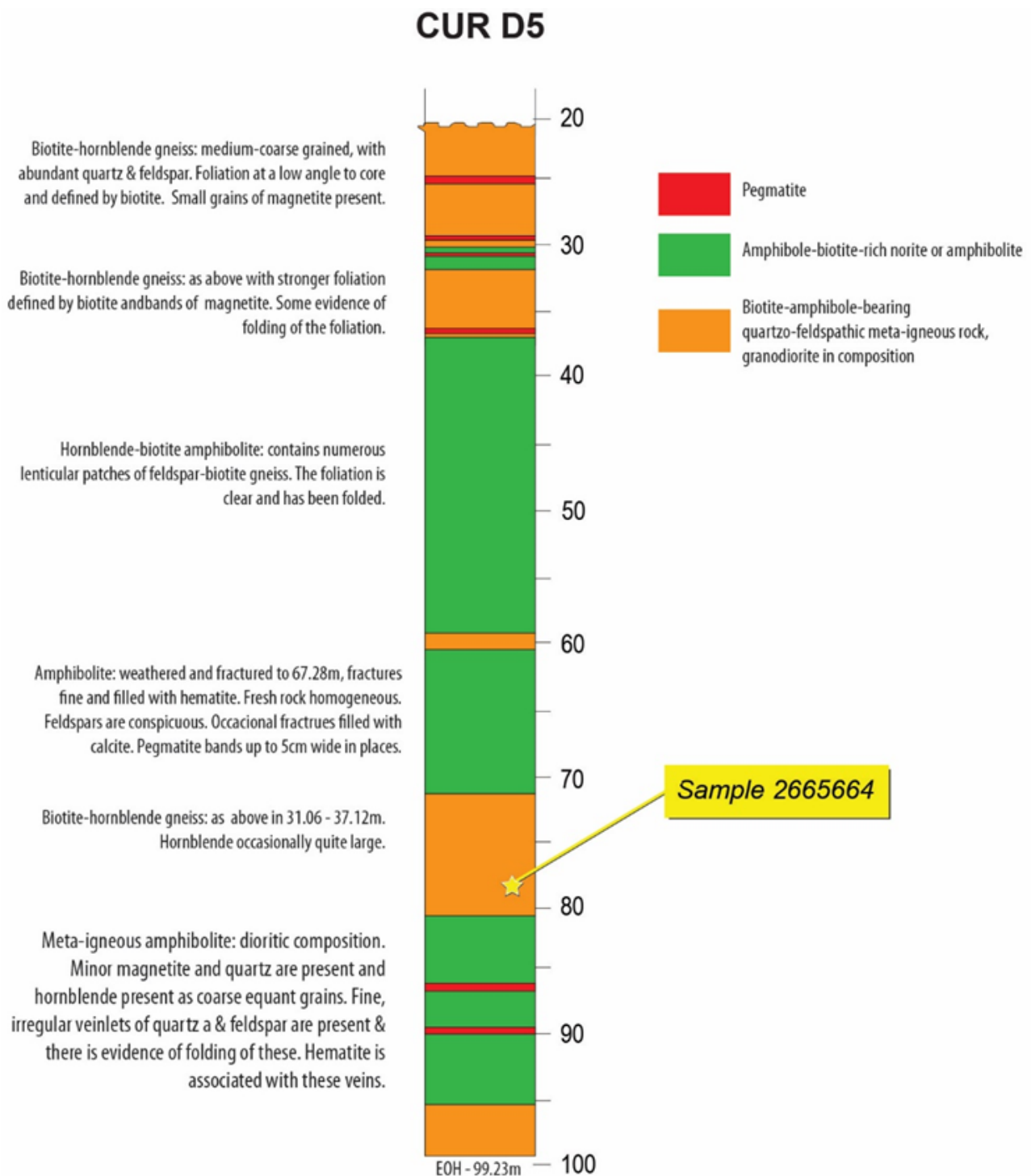
### SAMPLE INFORMATION

|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 2665664                                                                         |
| Collector:             | Wang, T                                                                         |
| Stratigraphic Unit:    | Moonta Porphyry Member                                                          |
| Location Lat-Long:     | -34.6133154 137.7609883                                                         |
| Location:              | Drillhole CUR D5, 78.5–78.9 m                                                   |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1737 ± 28 Ma                                                                    |
| Age type:              | Magmatic crystallisation age                                                    |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

### BACKGROUND

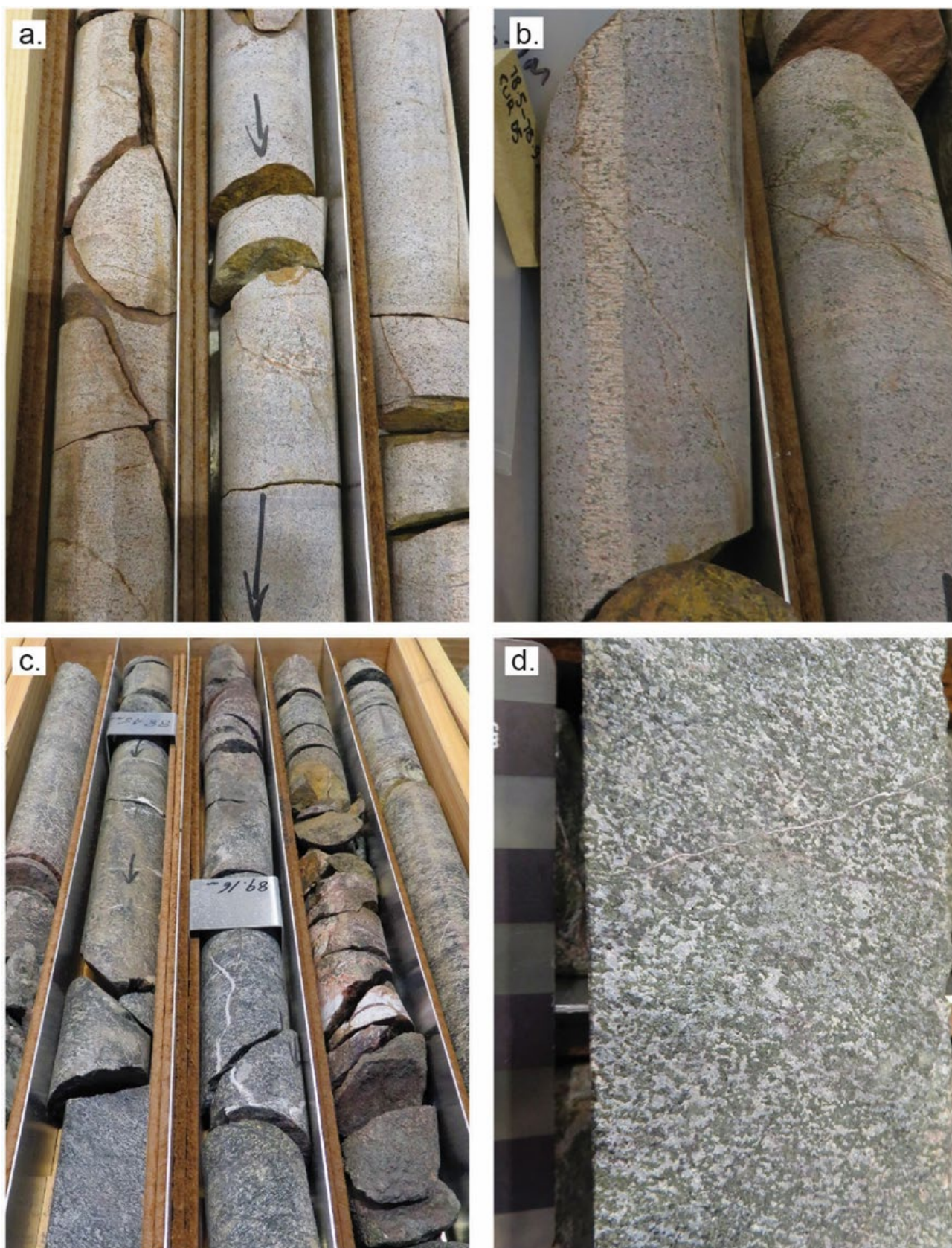
Drillhole CUR D5 was drilled on a gravity anomaly aiming to intersect iron oxide-copper-gold mineralisation (Roche et al., 1986). The drillhole intersected a biotite-amphibole-bearing meta-igneous rock of broadly diorite to granodiorite composition (Fig. 25). The more felsic portion of the drillhole includes foliated biotite-bearing quartz-plagioclase granodiorite (Fig. 26a). Sample 2665664 is from an interval of this medium- to fine-grained granodiorite (Fig. 26b).

Increased abundance of amphibole and biotite give rise to compositional variation from the more felsic granodiorite unit to hornblende-plagioclase-rich amphibolite (Fig. 26c, d). Petrographic description of a sample of amphibolite from 31 m depth indicates the unit is composed of amphibole (up to 50%), plagioclase (up to 35%) and quartz (5–10%). Minor K-feldspar (2–3 %), martitised magnetite (5–7 %), rare chlorite-aggregates after biotite, opaques and apatite are also present (Roche et al., 1986). The description notes the amphibole is also variably altered to chlorite aggregates. The amphibolite shows a preferred mineral orientation and in places this is noted to be folded. The compositional variation is gradational and feldspar-rich portions of rock occur within the amphibole-biotite-rich portions, suggesting the rock is a single igneous intrusive body with co-magmatic mafic and felsic variants.



**Figure 25. Schematic log of drillhole CUR D5 based on logging by Roche et al. (1986) and author observations.**



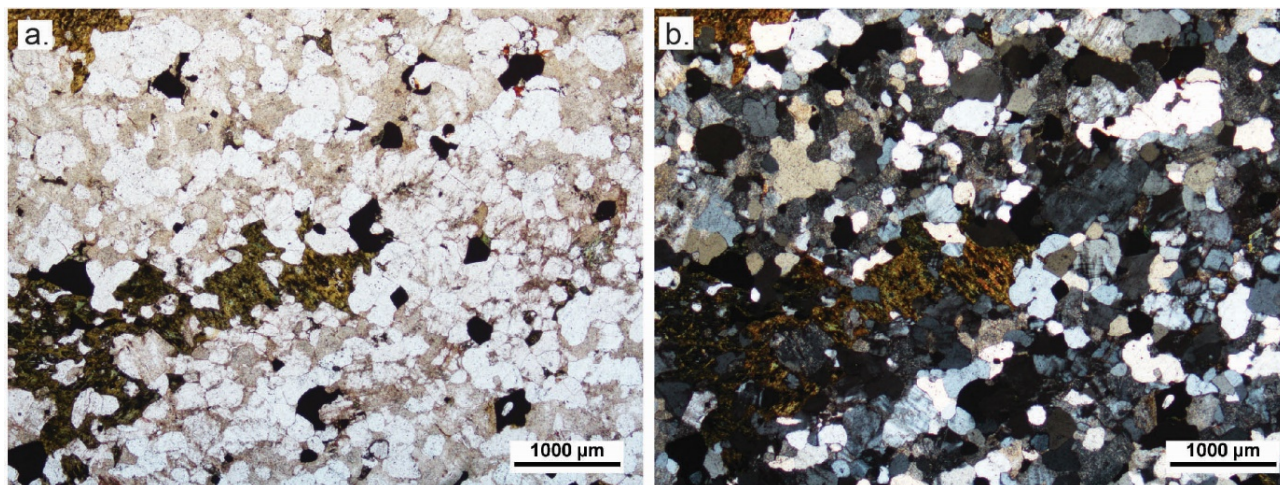


**Figure 26. Photographs of drillhole CUR D5. (a) Felsic unit from which sample 2665664 was selected. (b) Sample 2665664. (c) Mafic unit, or amphibolite. (d) Detail of mafic unit.**



## PETROGRAPHY

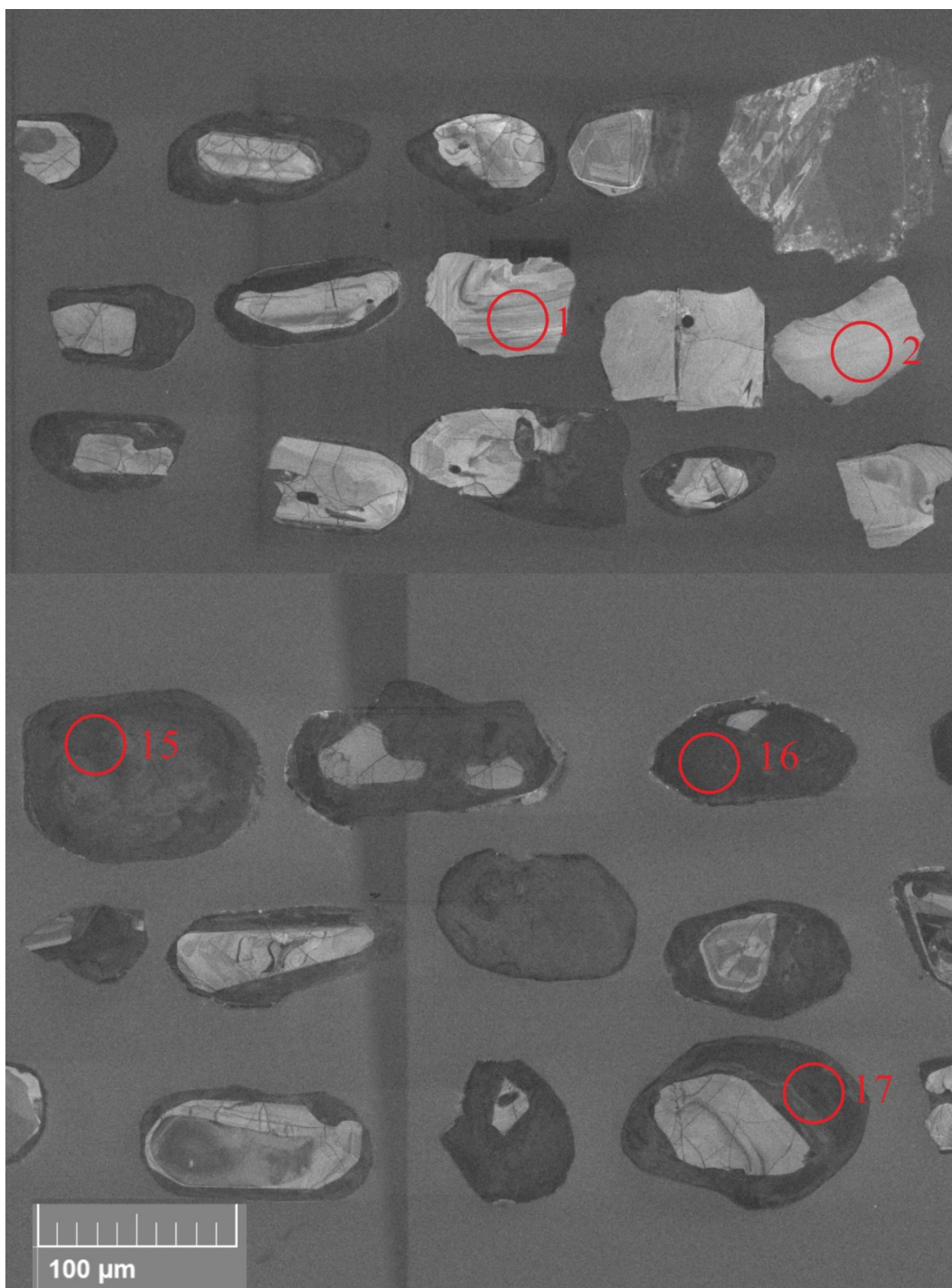
The thin section is dominated by dynamically recrystallised feldspar and quartz with chlorite-altered biotite aggregates and opaque species (Fig. 27). The quartz-feldspar matrix forms a broad preferred mineral orientation suggesting recrystallisation during deformation. Plagioclase is the dominant feldspar and extensively sericite altered. Lesser K-feldspar is present. Red colouration of the feldspars suggests microcrystalline hematite alteration. There are medium-grained opaque species comprising an estimated 5% of the rock volume and occurring interstitially to the quartz-feldspar matrix. In reflected light these are mostly magnetite grains that are partly or nearly completely oxidised to hematite. The magnetite appears to be an alteration mineral rather than a primary magmatic mineral due to the occurrence of inclusions of quartz in some of the magnetite grains and instances of irregular magnetite apparently wrapping quartz.



**Figure 27. Photomicrographs of sample 2665664. (a)** Transmitted plane polarised light.  
**(b)** Cross polars.

## ZIRCON CHARACTERISTICS

Zircons are variably fractured and blocky in shape with length to width ratios up to 3:1. A light CL response core is a common feature in zircons from this sample (Fig. 28). These core zones show features such as regular or semi-regular oscillatory zonation that suggests a magmatic origin. In almost all cases this light CL response core zone is surrounded by a dark CL response rim zone. This rim is, in some examples, weakly compositional zoned, while in others the CL response is indistinct and no zoning is apparent. In some instances the dark CL response appears to overprint or engulf the light CL response zones as if it is the result of metamorphic or fluid assisted recrystallisation. The dark CL response suggests high U content.



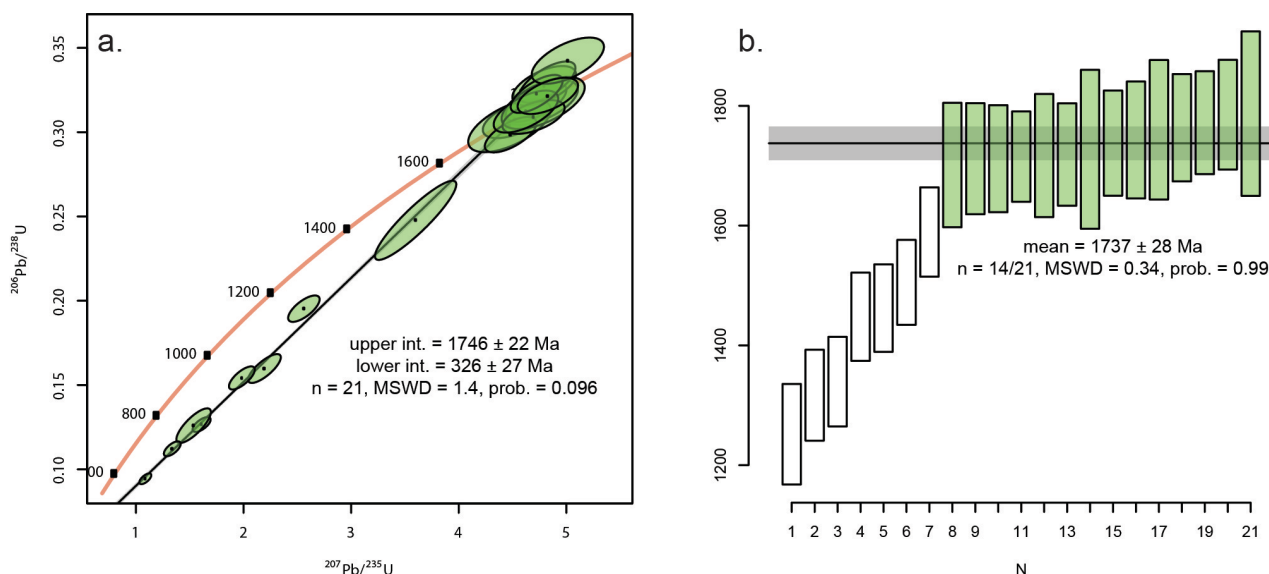
**Figure 28. Representative CL image of zircons from sample 2665664. Circles indicate analytical sites.**

## GEOCHRONOLOGICAL RESULTS

Twenty one zircons were analysed from sample 2665664, with the data indicating a single age population that has undergone Pb loss (Fig. 29a). The majority of the concordant analyses are from the light CL response domains. The discordant to strongly discordant analyses are from the dark CL response domains, and correspond to zircons with high U content and variable common Pb component. For example analysis -017, which has 1522 ppm U and a calculated common Pb value of 8.2 ppm.

A discordia line through all of the analyses produces a upper intercept age of  $1746 \pm 22$  Ma and a lower intercept of  $326 \pm 27$  Ma (MSWD = 1.4, prob. = 0.096; Fig. 29a). Excluding those analyses greater than 5% discordant yields a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1737 \pm 28$  Ma ( $n = 14$ , MSWD = 0.34, prob. = 0.99; Fig 29b). This weighted mean age is taken to indicate the timing of zircon crystallisation in this sample and time of formation of the granodioritic rock in drillhole CUR D5. The age indicates this sample could be part of the Moonta Porphyry Member, which was emplaced at c. 1750 Ma (Fanning et al., 2007).

The lack of age differentiation between the light and dark CL zones could indicate that the variation in zonation is a primary magmatic feature. A possible interpretation would be if the magma chamber underwent an episode of magma recharge leading to part resorption of existing zircon crystals and hence new precipitation of magmatic zircon around the older core domains. However, the overall increased REE values for the dark CL zones could indicate the dark zoned zircon is a result of hydrothermal alteration. This alteration could have occurred when other alteration minerals such as magnetite, chlorite and sericite were precipitated in the rock. Potentially, this alteration could be recorded by the lower intercept age of c. 326 Ma, which indicates non-recent Pb loss in the zircons. Further work on the alteration mineralogy of this rock such as via dating of apatite would be useful to determine the timing of alteration.



**Figure 29. Geochronology results for sample 2665664. (a)** Concordia diagram showing calculated discordia line. **(b)** Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation for the main age population within the sample.



## OORLANO METASOMATITE

### 3037026, K-feldspar-rich metasomatite, Oorlano Quarry

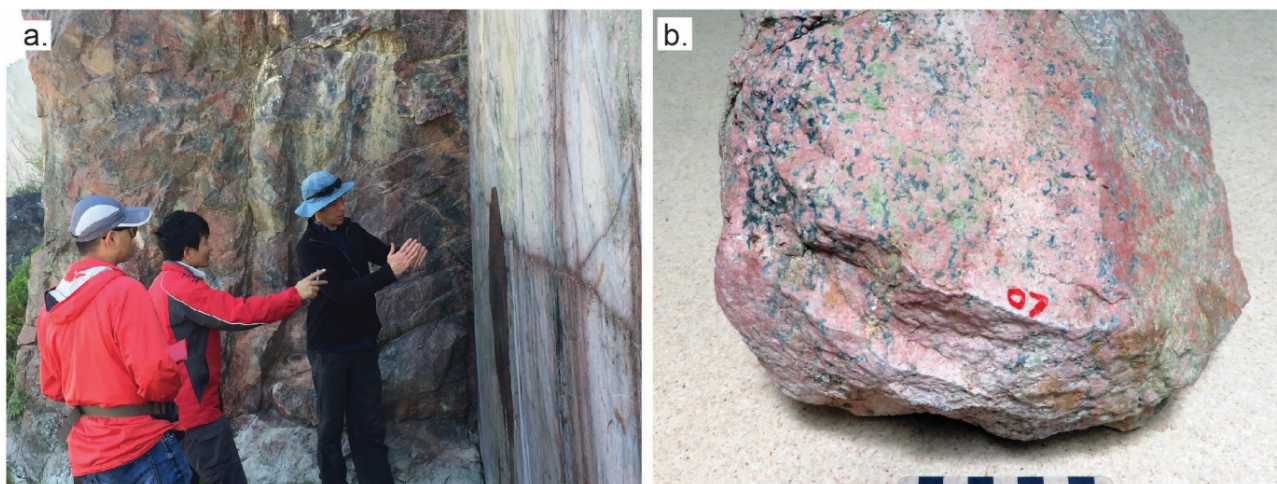
#### SAMPLE INFORMATION

|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 3037026                                                                         |
| Collector:             | Zhou, Y                                                                         |
| Stratigraphic Unit:    | Oorlano Metasomatite                                                            |
| Location Lat-Long:     | -33.907811 137.651516                                                           |
| Location:              | Oorlano Quarry, Yorke Peninsula                                                 |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1863 ± 35 Ma                                                                    |
| Age type:              | Maximum depositional age                                                        |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

#### BACKGROUND

Samples 3037026, 3037027 and 3037028 are all variants of the metasomatic rock found at the Oorlano Quarry, northern Yorke Peninsula (Fig. 30a). The quarry produces rock slabs as dimension stone known as Harlequin Stone (Conor, 1995). The stratigraphic unit is the Oorlano Metasomatite and represents a distinct unit on Yorke Peninsula. The Oorlano Metasomatite is a skarn-like metasomatic rock dominated by feldspar, amphibole and pyroxene together with variable amounts of epidote, magnetite, biotite, carbonate, pyrite and chalcopyrite (Cowley et al., 2003). Feldspar is dominantly albite, however, K-feldspar is also present.

Sample 3037026 is an example of feldspar (albite)-rich metasomatite (Fig. 30b).



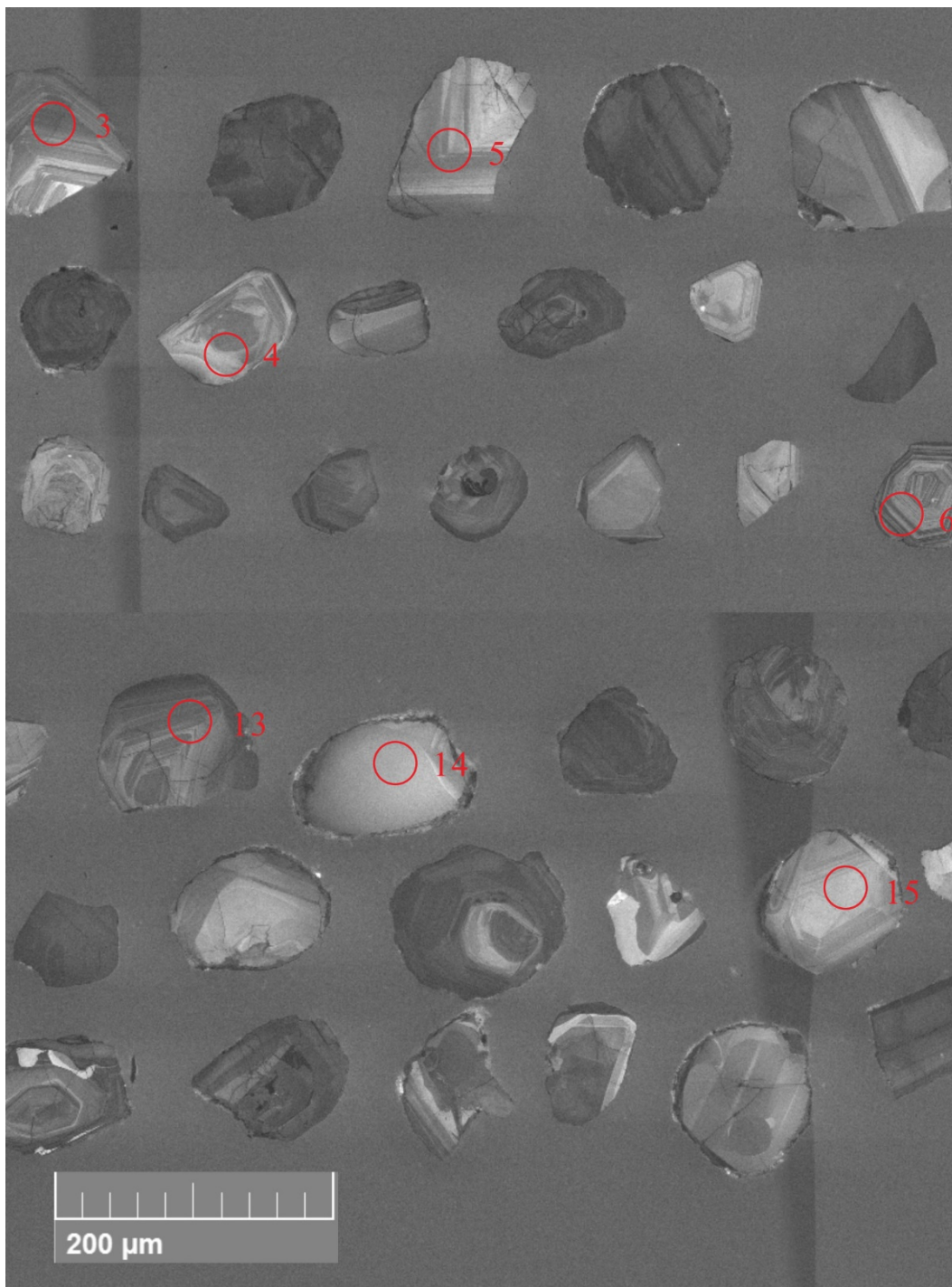
**Figure 30. Photographs of sample 3037026. (a) Field setting of Oorlano Metasomatite. (b) Sample 3037026.**

#### PETROGRAPHY

Not available for this sample.

#### ZIRCON CHARACTERISTICS

Zircons from this sample include rounded grains and fragments of grains, most having small length to width ratios, <3:1 (Fig. 31). The CL image reveals a variety of CL response from oscillatory zoned to broad, sector zoned to weak or no zoning. A few of the grains may have a narrow dark CL response rim, however, these are generally <20µm thick.



**Figure 31. Representative CL image of zircons from sample 3037026.** Circles indicate analytical sites.

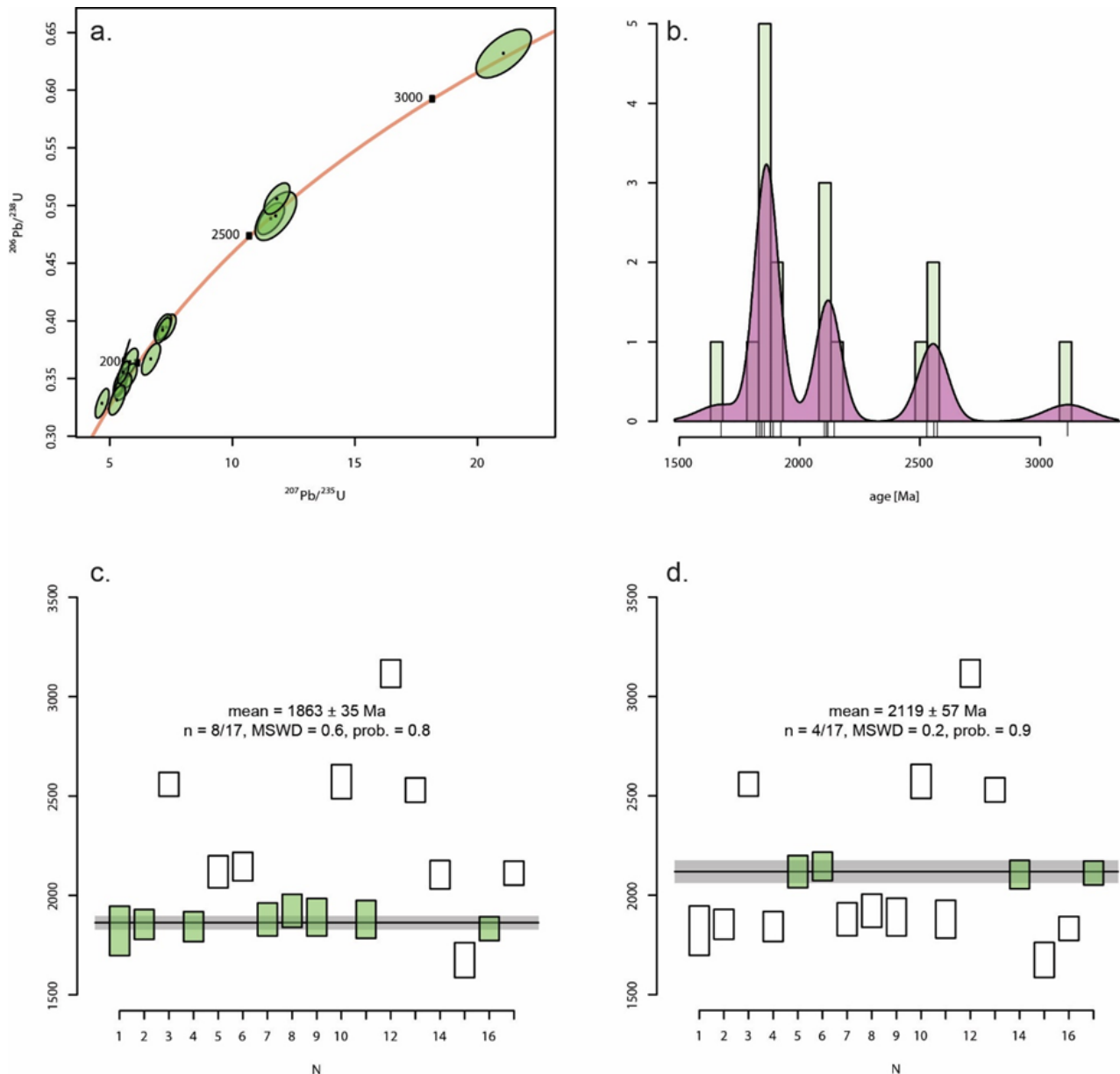
## GEOCHRONOLOGICAL RESULTS

Seventeen zircons were analysed from sample 3037026. The majority are concordant or near concordant and yield a range of  $^{207}\text{Pb}/^{206}\text{Pb}$  ages extending from  $3116 \pm 35$  Ma to  $1676 \pm 46$  Ma from analyses -012 and -015 respectively (Fig. 32a, b). There are three main clusters at c. 1860 Ma, c. 2120 Ma and at c. 2560 Ma. Calculation of weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for the two main populations indicate populations of zircon at  $1863 \pm 35$  Ma and  $2119 \pm 57$  Ma (Fig. 32c, d).

These data can be interpreted to be a spectrum of ages from detrital zircons. The main populations likely reflect the main source regions for the sediment, with the c. 1860 Ma population potentially correlating with the Donington Suite, and the c. 2560 Ma population with the Archean basement

rocks of the Gawler Craton such as the Devils Playground Volcanics. The c. 2120 Ma population is not from a source region of the Gawler Craton; no rocks of this age are known. However, we note that some c. 2100 Ma zircons are present in detrital populations in rocks such as the Corny Point Paragneiss (Howard et al., 2009).

A conservative maximum depositional age is  $1863 \pm 35$  Ma, representing the youngest population of zircon. However, the age of the youngest grain ( $1676 \pm 46$  Ma) could indicate that the protolith for the Oorlano Metasomatite was deposited after c. 1676 Ma. Further analyses are required to investigate this possibility.



**Figure 32. Geochronology results for sample 3037026. (a)** Concordia diagram. **(b)** Kernel density distribution. **(c)** Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation for the main age population within the sample. **(d)** Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation for the second significant age population in the sample.



## 3037027, amphibole+epidote-dominant metasomatite, Oorlano Quarry

### SAMPLE INFORMATION

|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 3037027                                                                         |
| Collector:             | Zhou, Y                                                                         |
| Stratigraphic Unit:    | Oorlano Metasomatite                                                            |
| Location Lat-Long:     | -33.907811 137.651516                                                           |
| Location:              | Oorlano Quarry, Yorke Peninsula                                                 |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1858 ± 26 Ma                                                                    |
| Age type:              | Maximum depositional age                                                        |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

### BACKGROUND

Sample 3037027 is an example of amphibole+epidote-dominant metasomatite from the Oorlano Quarry, northern Yorke Peninsula (Fig. 33).

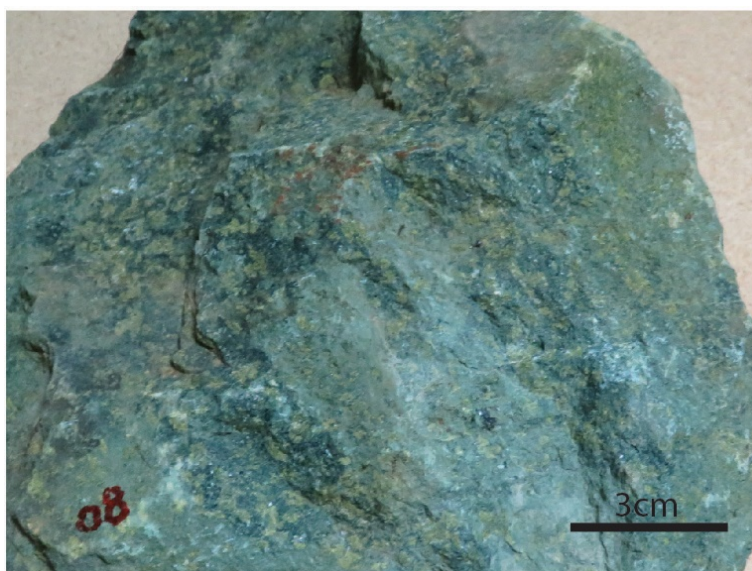


Figure 33. Photograph of sample 3037027.

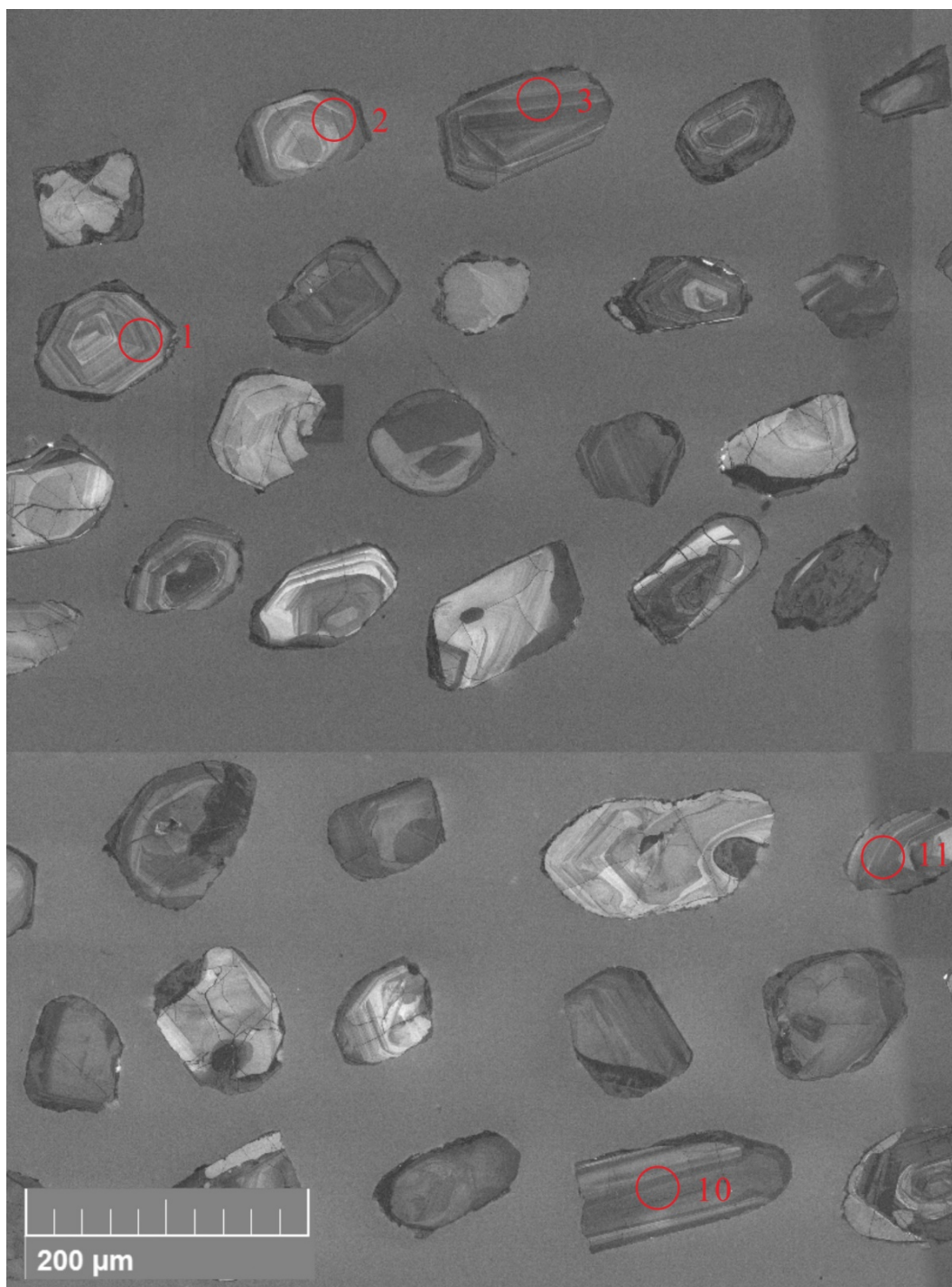
### PETROGRAPHY

Not available for this sample.

### ZIRCON CHARACTERISTICS

Zircons from this sample are angular to rounded in shape and have a variety of length to width ratios, up to 4:1 (Fig. 34). The CL response is similarly varied, from oscillatory zoned to sector zoned to weak or broad zonation. Some grains have core-rim structures, however, these were not able to be analysed due to the size of the laser ablation spot.



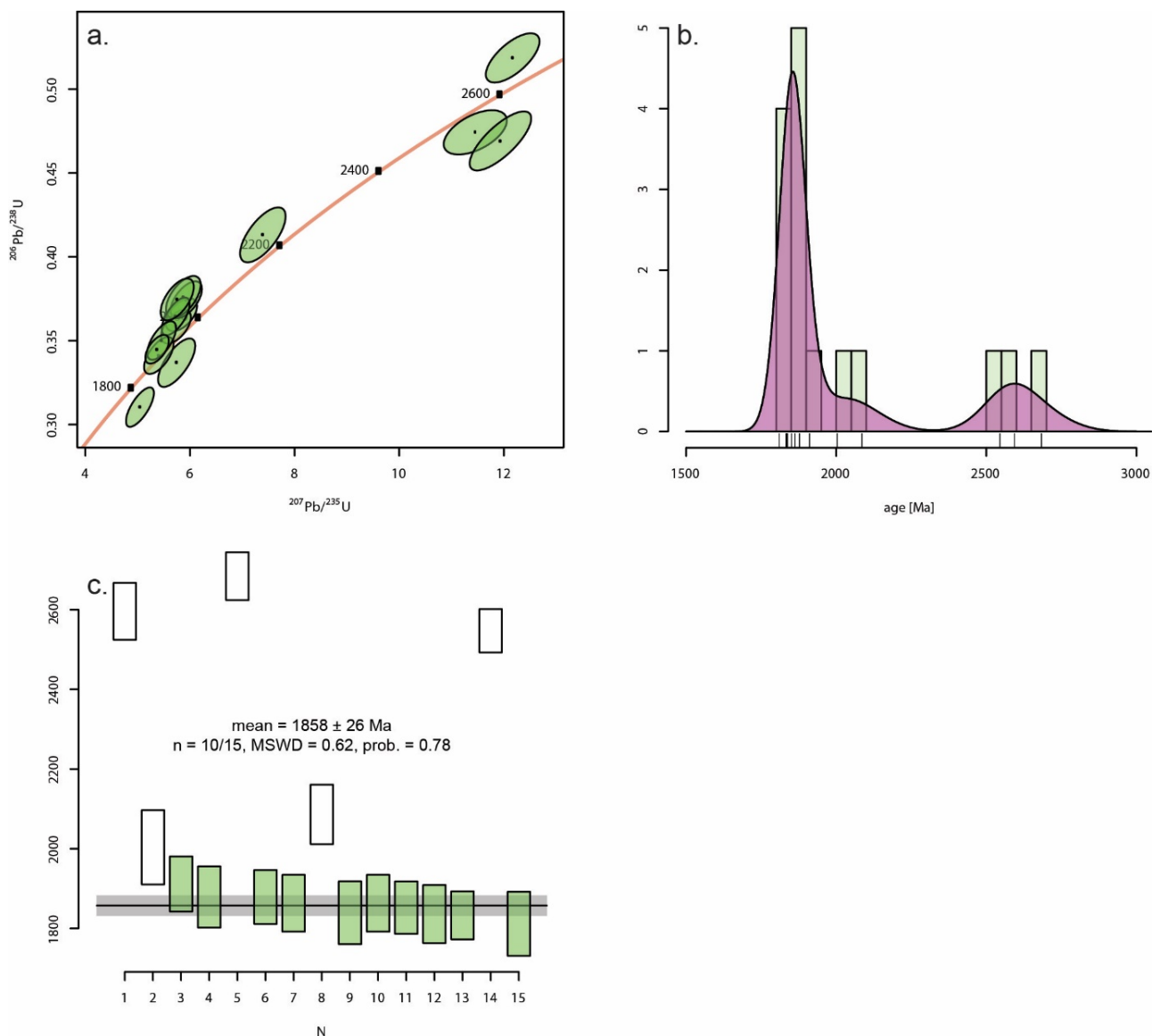


**Figure 34. Representative CL image of zircons from sample 3037027. Circles indicate analytical sites.**

## GEOCHRONOLOGICAL RESULTS

Fifteen zircons were analysed from sample 3037027. The data are mostly concordant and range in age from a maximum of  $2685 \pm 31$  Ma to a minimum of  $1813 \pm 41$  Ma (Fig. 35a, b). There are three late Archean analyses, two analyses at around c. 2000 Ma and a major age population is at c. 1860 Ma. A weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1858 \pm 26$  Ma defines the main age population from 10 analyses (MSWD = 0.62, prob. = 0.78; Fig. 35c).

The age spectrum is consistent with a detrital age population, and the main age at  $1858 \pm 26$  Ma defines a maximum depositional age for this sample.



**Figure 35. Geochronology results for sample 3037027. (a)** Concordia diagram. **(b)** Kernel density distribution. **(c)** Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation for the main age population within the sample.

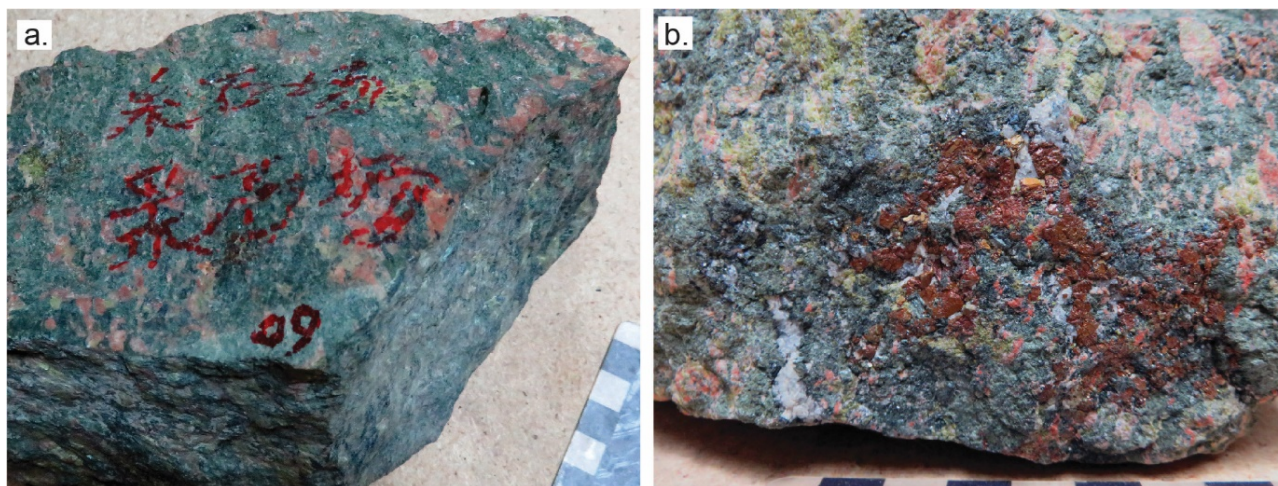
## 3037028, chalcopyrite-bearing metasomatite, Oorlano Quarry

### SAMPLE INFORMATION

|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 3037028                                                                         |
| Collector:             | Zhou, Y                                                                         |
| Stratigraphic Unit:    | Oorlano Metasomatite                                                            |
| Location Lat-Long:     | -33.907811 137.651516                                                           |
| Location:              | Oorlano Quarry, Yorke Peninsula                                                 |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1755 ± 36 Ma                                                                    |
| Age type:              | Maximum depositional age                                                        |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

### BACKGROUND

Sample 3037028 is an example of mineralised, chalcopyrite+pyrite-bearing metasomatite from the Oorlano Quarry, northern Yorke Peninsula (Fig. 36).



**Figure 36. Photographs of sample 3037028. (a) Sample 3037028. (b) Detail of sulphide within sample 3037028.**

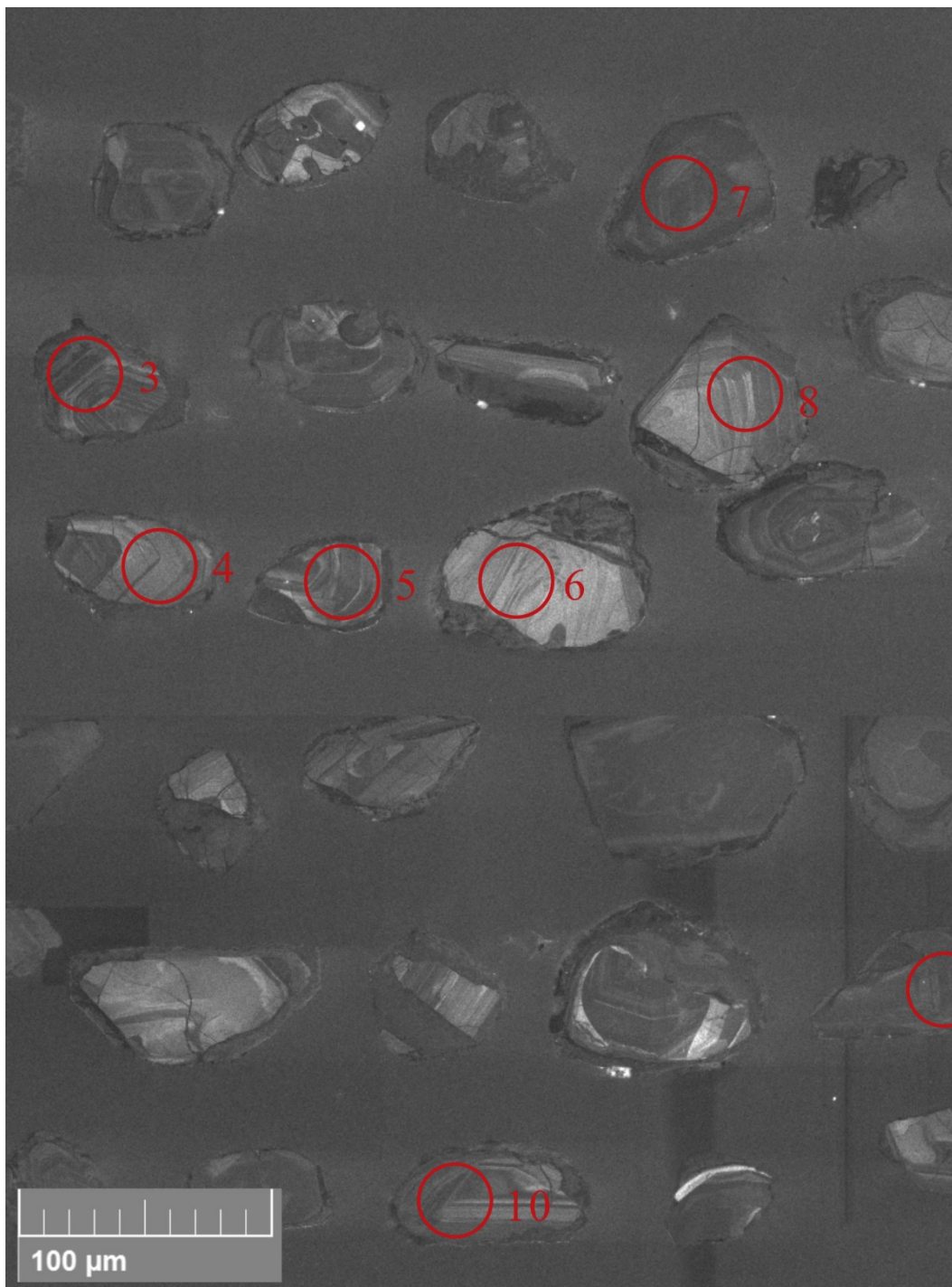
### PETROGRAPHY

Not available for this sample.

### ZIRCON CHARACTERISTICS

Zircons from this sample have a variety of shapes from rounded to angular, and length to width ratios that vary between 1:1 to 4:1 (Fig. 37). The zircons have a variety of CL response, and include oscillatory zoned zircon with light CL response, to darker CL response zircon with weak zonation, or more sector-like CL response. Many of the grains have ragged, disrupted CL response portions, suggestive of a metamict crystal lattice. A narrow dark CL response rim is evident on some of the grains, although this is generally <20µm and was not analysed.





**Figure 37. Representative CL image of zircons from sample 3037028.** Circles indicate analytical sites.

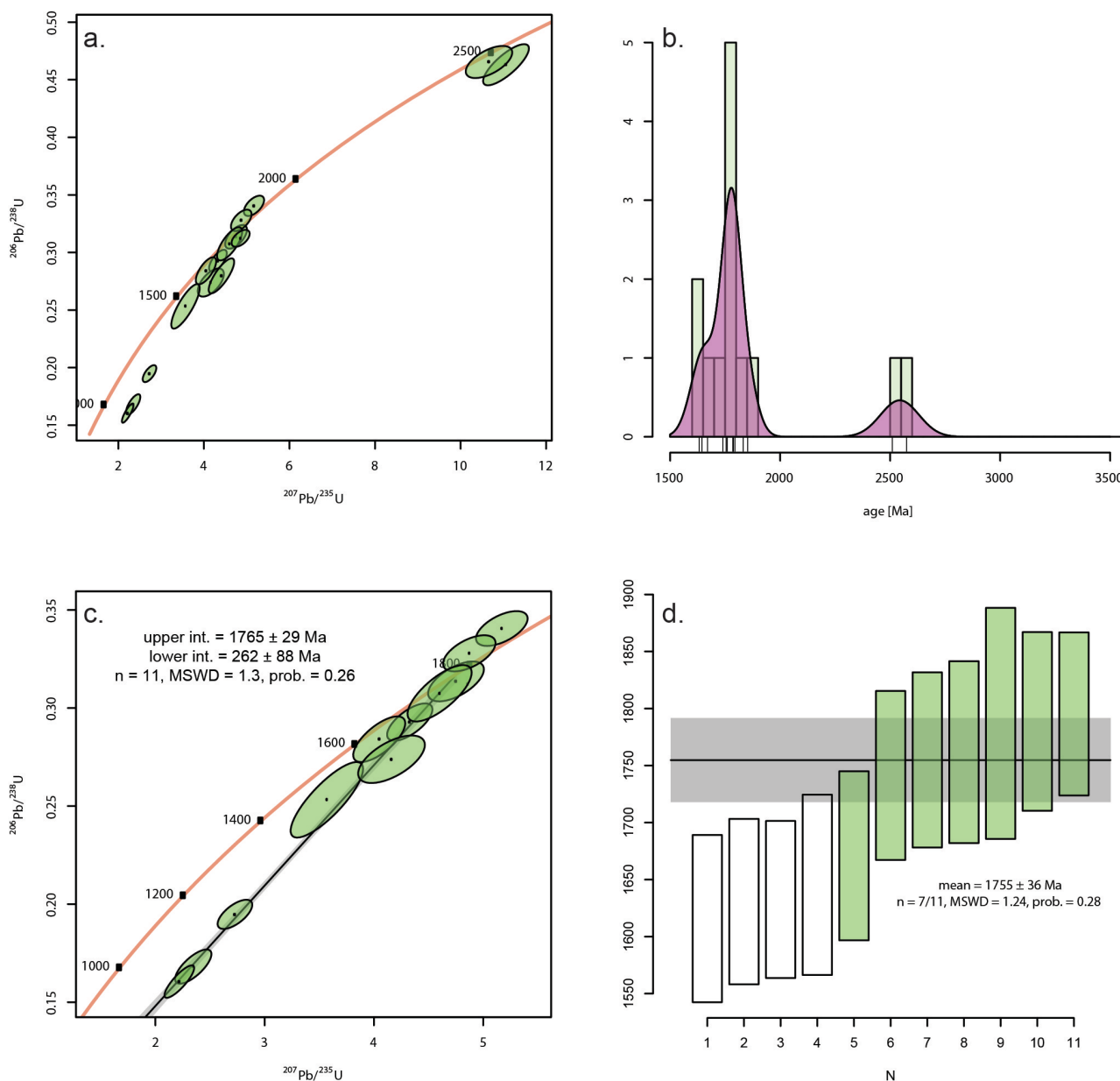
## GEOCHRONOLOGICAL RESULTS

Fifteen zircons were analysed from sample 3037028. The data range from concordant to strongly discordant (Fig. 38a). The majority of  $^{207}\text{Pb}/^{206}\text{Pb}$  ages are between 2550 Ma and c. 1670 Ma (Fig. 38b).

Within this, there is a grouping of two analyses with ages c. 2550 Ma (analyses -001 and -009) and second grouping of two analyses with ages of c. 1840 Ma (analyses -002 and -007). The youngest 11 analyses define a discordia with an upper intercept of  $1765 \pm 29$  Ma and a lower intercept of  $262 \pm 88$  Ma (MSWD = 1.3, prob = 0.26). The lower intercept suggests the discordance is a result of non-recent Pb loss, possibly during the Permian.

Omitting the four younger, discordant analyses, the youngest age population can be defined by 7 analyses with a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1755 \pm 36$  Ma (MSWD = 1.24, prob. = 0.28; Fig. 38c).

The zircon data indicate a detrital age spectrum with a minor late Archean component, and a Paleoproterozoic component dominated by zircons with age similar to the Donington Suite (c. 1850 Ma) and to other volcanic and/or volcanoclastic units of the Wallaroo Group (c. 1770 Ma). A conservative maximum depositional age for this sample is  $1755 \pm 36$  Ma. A single near concordant analysis at c. 1672 Ma is similar to another grain from sample 3037027 which has a very similar age of  $1676 \pm 46$  Ma. It is possible that c. 1675 Ma could represent a younger detrital population, or these grains could simply have been affected by some degree of Pb loss, possibly during the metasomatic event that pervasively altered the precursor rock type.



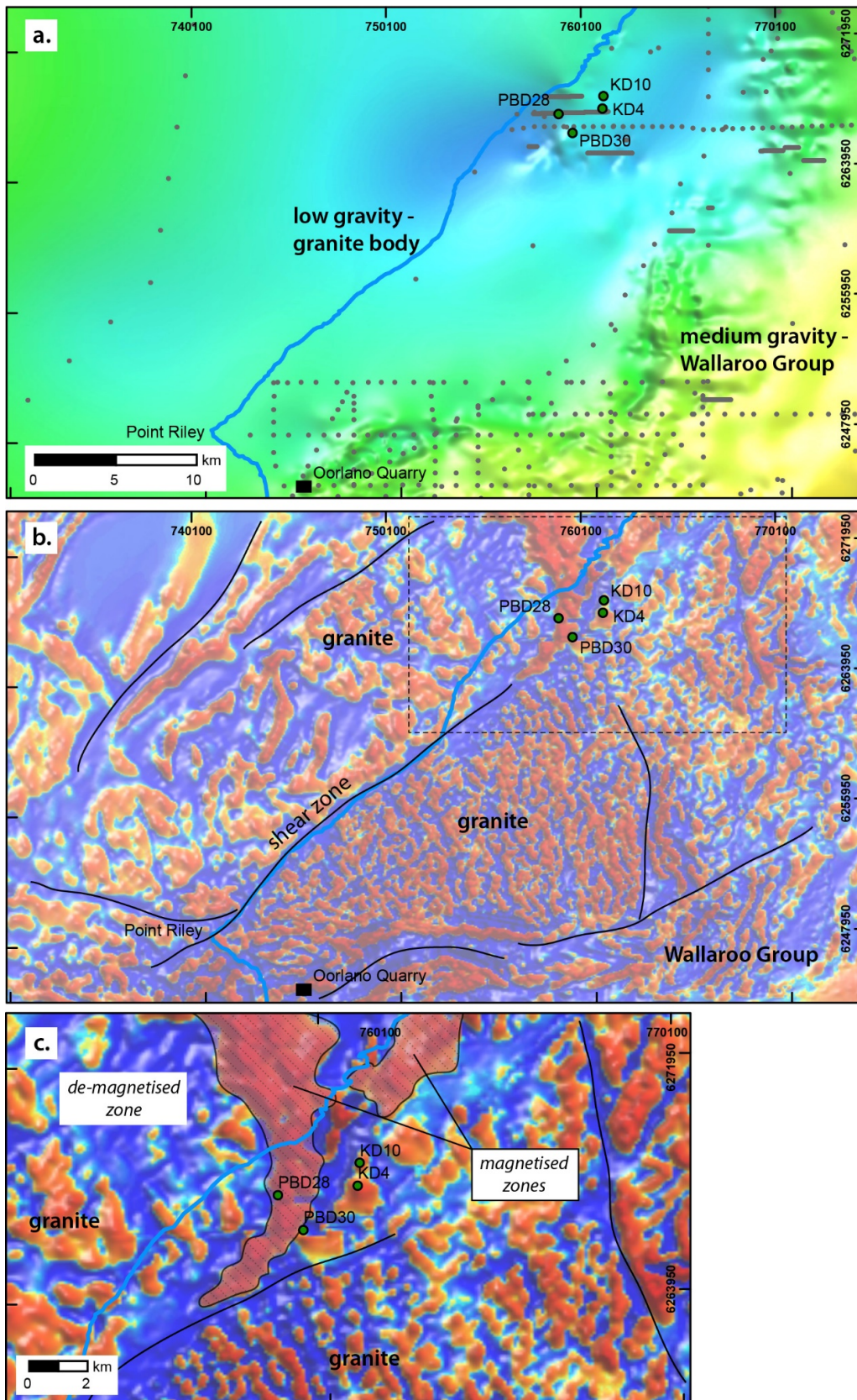
**Figure 38. Geochronology results for sample 3037028. (a) Concordia diagram. (b) Kernel density distribution. (c) Discordia calculation for the main population of zircons. (d) Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation for the main age population within the sample.**

## **MAGMATIC ROCKS OF THE NORTH-WESTERN YORKE PENINSULA**

Four drillholes were sampled from the region to the northeast of Point Riley, north of Wallaroo (Figs 1, 39). These drillholes from historical EL 1199 targeted iron oxide-copper-gold mineralisation based on a gravity anomaly. Samples of granite were collected for geochronology in order to investigate the timing of magmatism in this area.

The geophysical response for this region reveals a large region of low gravity that corresponds to a granitic body in the shallow crust (Fig. 39). The granite body intrudes Wallaroo Group metasedimentary and meta-igneous rocks, which have a generally higher gravity response (Fig. 39a). Detailed first vertical derivative images for the region reveal the granitic bodies have a complex magnetic response, likely a result of complex fault systems and the redistribution of magnetite in these fault networks (Fig. 9b). However, it is also clear that the region of the sampled drillholes has an unusual, broader and higher tenor magnetic texture that likely images the magnetite-bearing metasomatism that is evident in the drillholes. In addition, this high magnetic response ridge is adjacent to a zone of relatively lower magnetic intensity that could be a result of magnetite destructive alteration (Fig. 39c). Also of note is the magnetic discontinuity that runs parallel to the coastline between regions of subtly different magnetic response. This shear zone is exposed in the foliated granites at Point Riley that have been discussed in detail recently by Brotodewo et al. (2018)





**Figure 39. Geophysical setting for drillholes northeast of Point Riley sampled in this study.** All geophysical data, images and metadata are available via SARIG, <https://map.sarig.sa.gov.au/>. (a) Bouguer Anomaly gravity image. Also indicated are location of gravity measurements (grey circles). (b) First vertical derivative grid derived from total magnetic intensity (reduced to pole) grid of South Australia. This image was produced using a Fast Fourier Transform. (c) Detail of first vertical derivative grid in the vicinity of the sampled drillholes. Overlay indicates presence of magnetised and demagnetised zones. Linear features indicated are interpreted to be discrete shear zones.

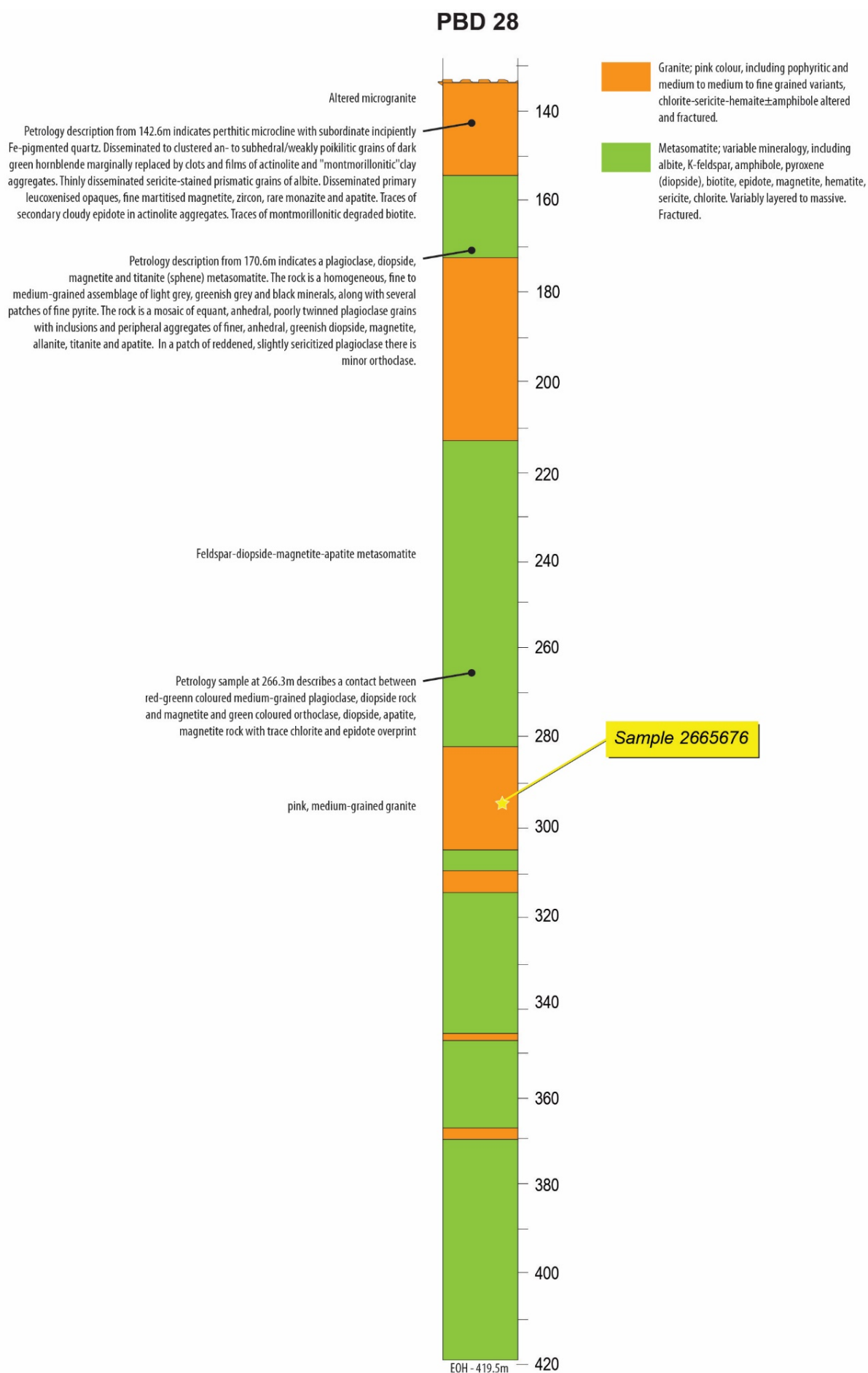
## 2665676, granite, drillhole PBD 28, 294–295.4 m

### SAMPLE INFORMATION

|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 2665676                                                                         |
| Collector:             | Zhao, Y                                                                         |
| Stratigraphic Unit:    | Spilsby Suite                                                                   |
| Location Lat-Long:     | -33.7014399 137.7923317                                                         |
| Location:              | Drillhole PBD 28, 294–295.4 m                                                   |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1513 ± 26 Ma                                                                    |
| Age type:              | Magmatic crystallisation age                                                    |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

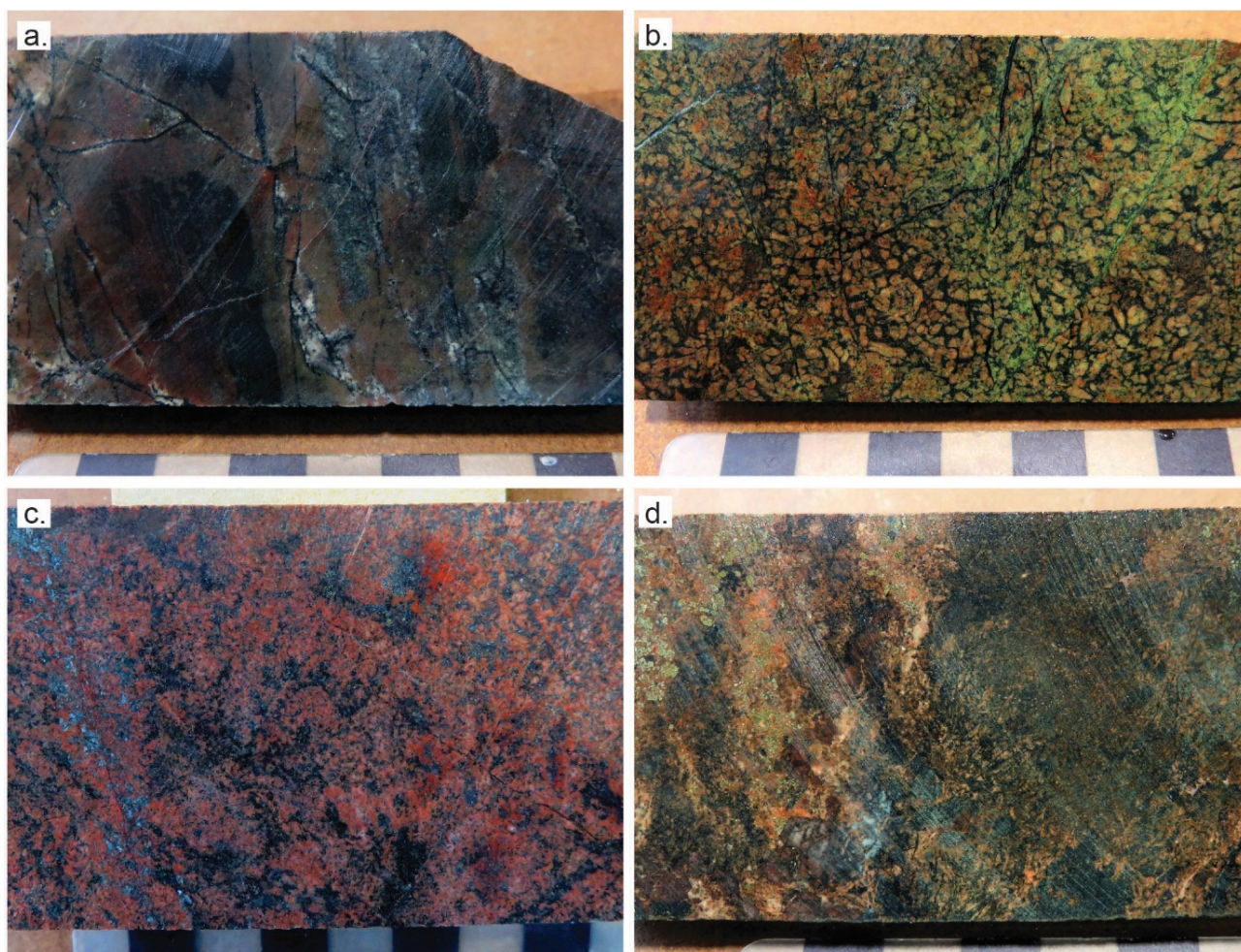
### BACKGROUND

Drillhole PBD 28 intersected metasomatic rocks interlayered with less altered igneous rocks of quartz monzonite composition (Fig. 40; Coles et al., 1991). In some places the metasomatic rocks include compositional layering that could be metasedimentary in origin (Fig. 41a). Other metasomatic rocks include coarse albite-rich assemblages (Fig. 41b). We note that petrographic descriptions from the original drilling reports describe allanite and apatite occurring in association with the plagioclase-rich alteration assemblages. In places, these coarse plagioclase assemblages are overprinted by more K-feldspar and magnetite-rich assemblages (Fig. 41c). Sulphides are present, predominantly pyrite with lesser chalcopyrite, and appear to occur in association with chlorite (Fig. 41d). Taken together, the rock fabrics and mineral assemblages in drillhole PBD 28 suggest pre-existing metasedimentary units were overprinted by high temperature Na-rich fluids and subsequently lower temperature K-Fe-rich fluids. These progressive alteration assemblages are similar to those described in detail by Corriveau et al. (2016) from Canadian examples. Further study of the alteration systems of this drillhole and drillholes in the PBD series from the northern Yorke Peninsula are likely to demonstrate the systematic nature of the alteration assemblages and could be key to understanding where the more sulphide-rich assemblages are likely to be, based on the abundance of the lower temperature alteration minerals.



**Figure 40. Schematic log of drillhole PBD 28 based on logging by Coles et al. (1991) and author observations. Brief summary of petrology descriptions are from Coles et al. (1991).**





**Figure 41. Photographs of metasomatic rocks of drillhole PBD 28.** (a) Albite-rich alteration that overprints apparently layered rock. Fractures filled with carbonate and hematite are also present, 348 m. (b) Feldspar- and biotite-rich alteration. Green overprint suggests secondary chlorite-rich alteration, 365.5 m. (c) Red K-feldspar and iron oxide alteration. This alteration has a different texture to a portion of the rock in the top right-hand side of the image that has a similar texture to the coarse feldspar alteration evident in the previous image. This suggests an overprint of K-Fe rich fluid. Note the shiny hematite-rich band of alteration in the left-hand side of this image, 379 m. (d) Green, chlorite-rich alteration in association with sulphide and hematite, 264 m.

Granitic rocks are also present in drillhole PBD 28. The granitic rocks are moderately altered and also show evidence for weak deformation and fracturing. Petrographic descriptions in the original drilling reports suggest the granitic rocks have undergone actinolite-epidote-sericite alteration with partial argillic alteration of the secondary amphibole apparently contemporaneous with microfracturing (see page 2718 of Coles et al., 1991). Sample 2665676 is a quartz monzonite from drillhole PBD 28 (Fig. 42).

## PETROGRAPHY

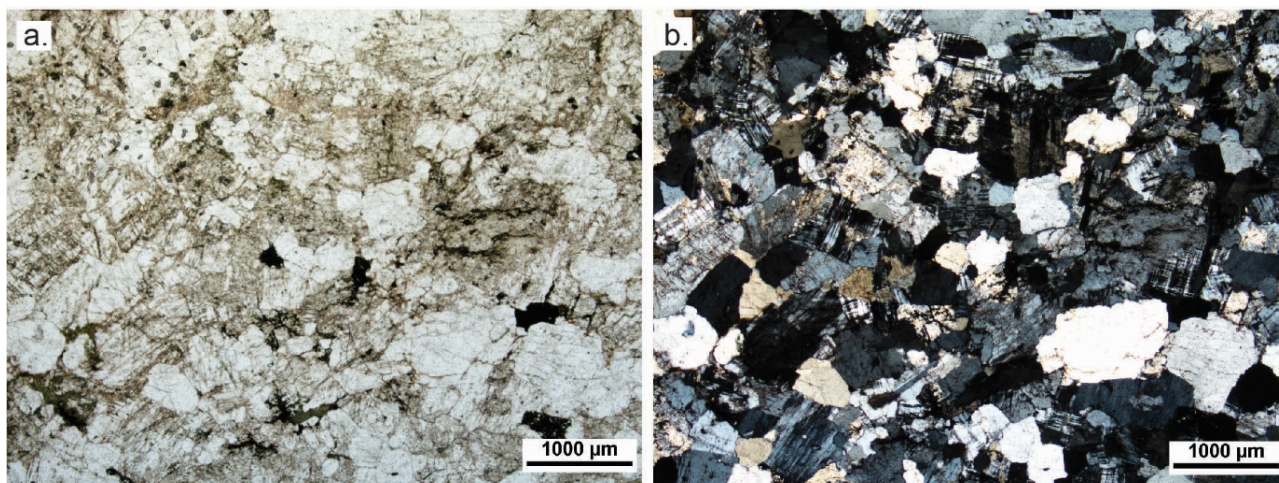
The sample is a medium-grained granite with an equigranular texture (Fig. 43). Quartz is generally undeformed, although some undulose extinction is present. Feldspar is dominantly K-feldspar as evidenced by abundant multiply twinned grains, although plagioclase is also present. Feldspar is variably altered, with sericite and a reddish tinge, likely hematite dusting. Biotite occurs as clots that are altered to chlorite. Opaque minerals are present including magnetite and pyrite.





**Figure 42. Photograph of sample 2665676, granitic rock from drillhole PBD 28.**

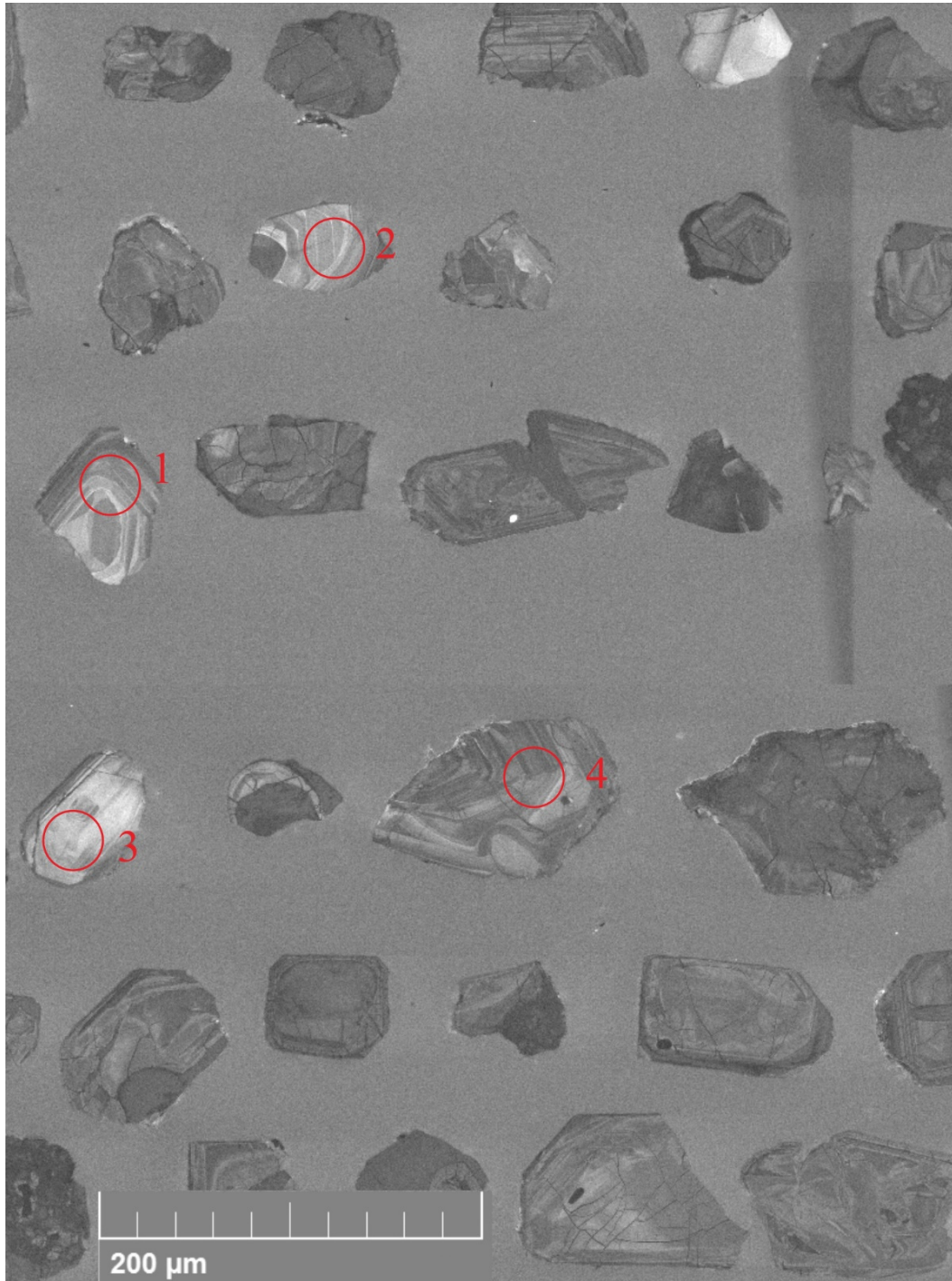
Petrographic description from the original drilling report of a sample from 281 m depth suggest a very similar rock type (see page 2915 of Coles et al., 1991). The report describes an altered microgranite which comprises aggregates of cloudy granular (mean 150  $\mu\text{m}$ ), strongly Fe-pigmented K-feldspar, pseudomorphous after initially coarser grained (mean 500  $\mu\text{m}$ ) prismatic laths, with interspersed clots and vaguely pseudomorphous aggregates of fine-grained variably chloritised amphibole and subordinate cloudy epidote. Irregular aggregates of similarly altered amphibole, apatite and epidote with interspersed and marginal spongy clusters of pyrite, disseminated cloudy fine-grained titanite and minor Fe-pigmented K-feldspar (poorly determinate but apparently adularia). Accessory minerals include disseminated very fine magnetite concentrated in secondary amphibole-epidote-apatite aggregates with traces of similarly distributed ultrafine-grained sulphide (pyrite). The original report interprets the rock as an extensively recrystallised and altered felsic intermediate (e.g. syenitic) intrusive that displays metasomatic effects with the primary ferromagnesian silicates replaced by aggregates of amphibole, epidote, apatite and locally pyrite, with the amphibole being variably replaced by late chlorite.



**Figure 43. Photomicrographs of sample 2665676. (a) Transmitted plane polarised light. (b) Cross polars.**

## ZIRCON CHARACTERISTICS

Zircons from this sample are generally blocky in shape, with low length to width ratios and strongly cracked. The zircons predominantly display a dark CL response, with many grains having indistinct, irregular banding suggestive of metamict zircon (Fig. 44). Some grains have brighter CL response and these have largely been targeted for geochronology analysis. These lighter CL response grains have oscillatory zonation typical of igneous zircon.

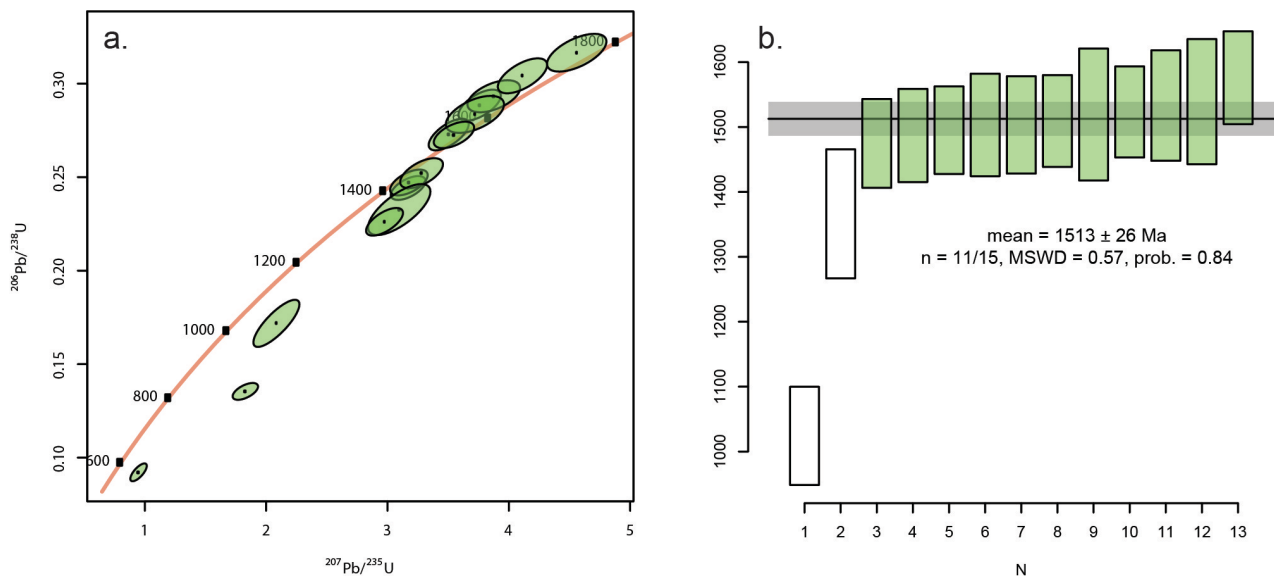


**Figure 44. Representative CL image of zircons from sample 2665676. Circles indicate analytical sites.**



## GEOCHRONOLOGICAL RESULTS

Fifteen zircons were analysed from sample 2665676. While most are concordant or near concordant, there are several analyses that are significantly discordant (Fig. 45a). Analysis -003 lies outside the main age population having a  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1698 \pm 39$  Ma. The main age cluster lies at around c. 1515 Ma. Pooling those analyses with <10% discordance yields a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1513 \pm 26$  Ma ( $n = 11/15$ , MSWD = 0.57, prob. = 0.84; Fig. 45b). This age is interpreted to be the timing of magmatic crystallisation of the sample. This age is similar in timing to the Spilsby Suite of the southern Gawler Craton (Fanning et al., 2007). As the granite is only weakly altered, it suggests the main alteration assemblages of drillhole PDB 28 formed prior to c. 1513 Ma. The  $1698 \pm 39$  Ma grain in this granite is likely inherited from the source region, possibly Wallaroo Group or syn-Kimban Orogeny granite such as the Peter Pan Supersuite or equivalent.



**Figure 45. Geochronology results for sample 2665676. (a) Concordia diagram. (b) Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation.**



## 2665675, augen textured granite, drillhole PBD 30, 119.4–120.4 m

### SAMPLE INFORMATION

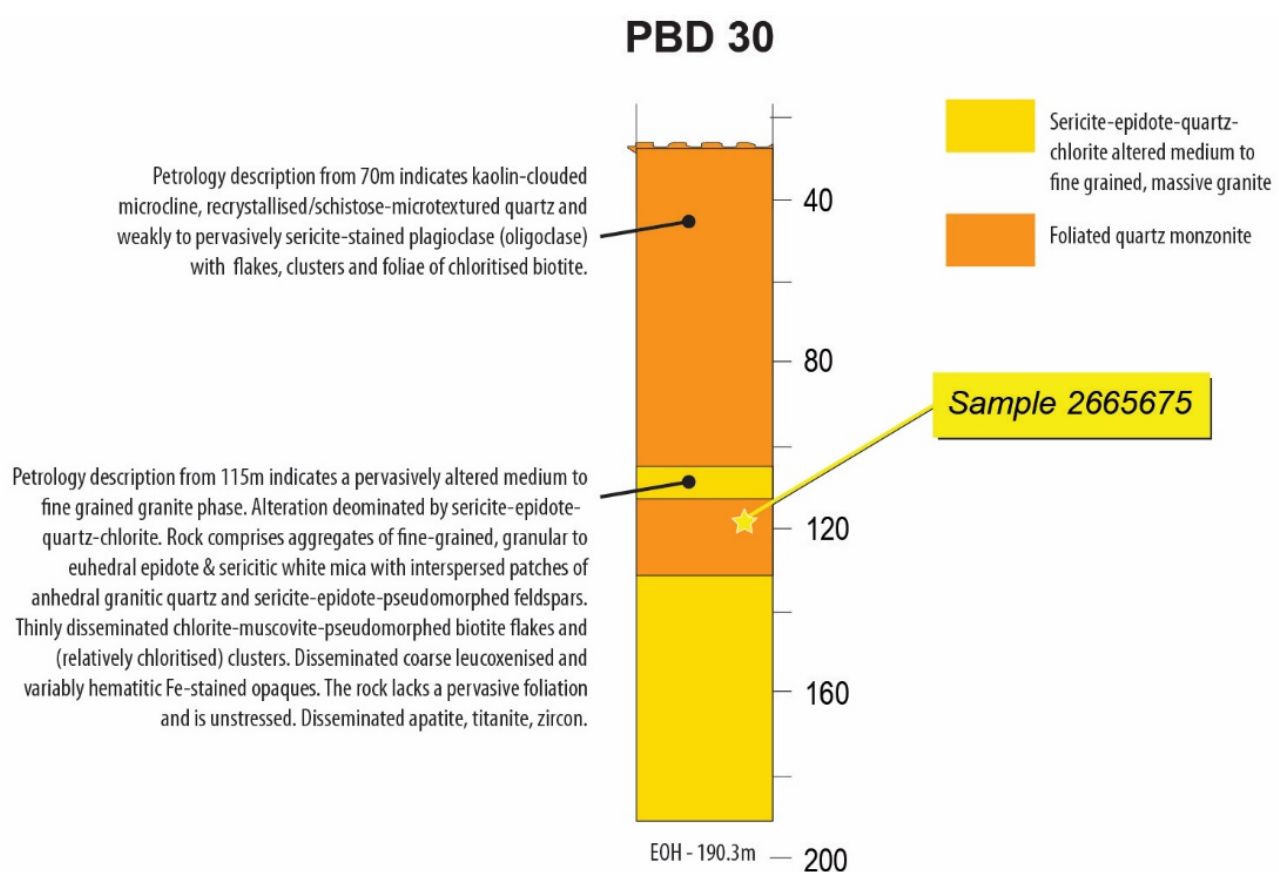
|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 2665675                                                                         |
| Collector:             | Zhao, Y                                                                         |
| Stratigraphic Unit:    | Tickera Granite, Hiltaba Suite                                                  |
| Location Lat-Long:     | -33.7120819 137.8000678                                                         |
| Location:              | Drillhole PBD 30, 119.4–120.4 m                                                 |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1576 ± 25 Ma                                                                    |
| Age type:              | Magmatic crystallisation age                                                    |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

### BACKGROUND

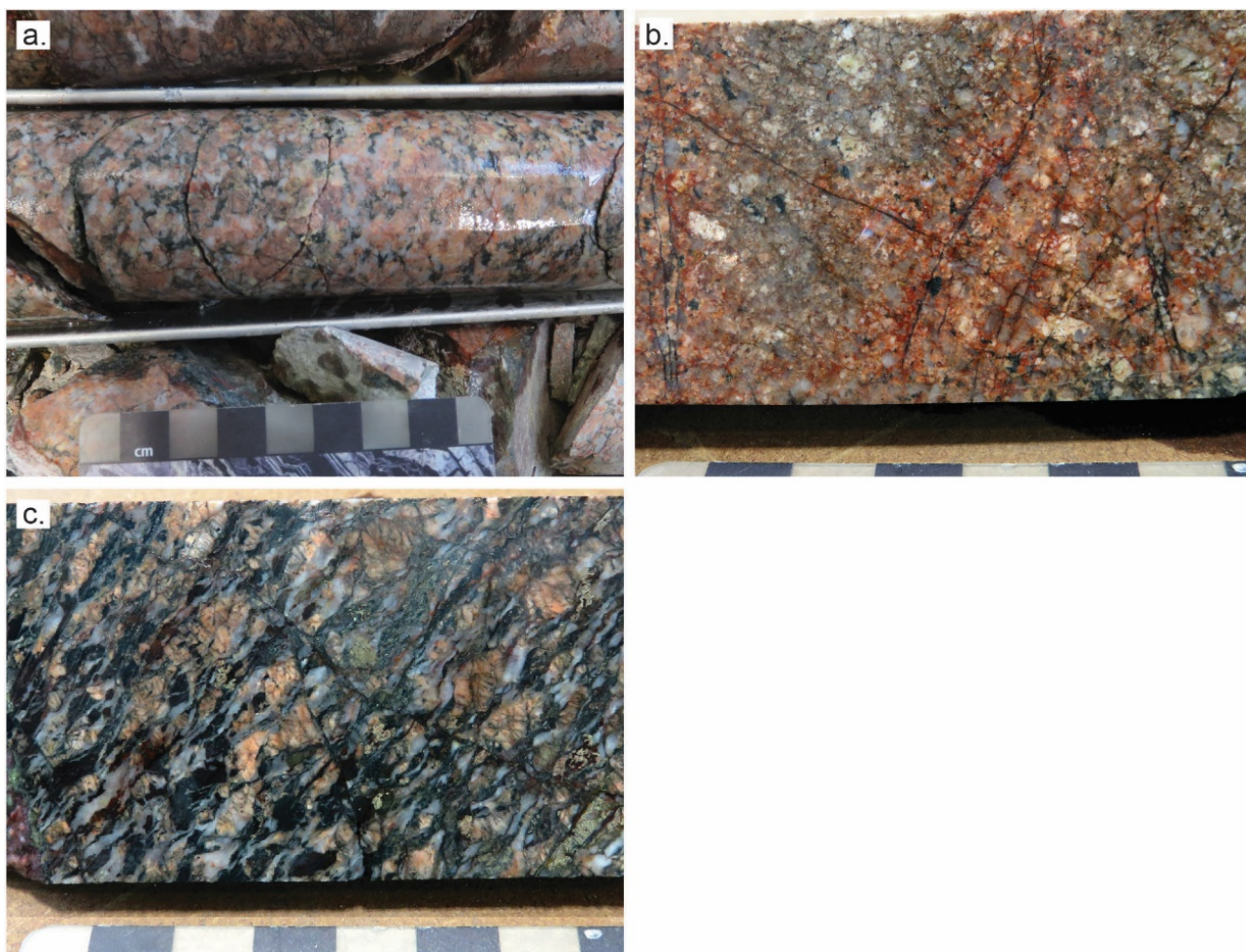
Drillhole PBD 30 intersected two phases of granitic rock (Fig. 46). The first is a variably altered augen textured granite. This augen granite is typically foliated, with quartz ribbons (Fig. 47a). Petrographic description from the drilling report shows the rock to be dominantly quartz-biotite-monzonite in composition, accessory mineral assemblage comprising leucoxenised opaques, apatite, metamict monazite and zircon (Coles et al., 1991). The alteration in this drillhole is of variable intensity and includes sericite-chlorite(±hematite), epidote-sericite-quartz and amphibole-bearing alteration assemblages.

The second granite phase is finer-grained and lacks the pervasive, ductile recrystallisation of the augen granite, being deformed by brittle fractures only (Fig. 47b). This granite phase has a porphyritic texture and is pervasively altered by sericite-chlorite (±hematite), epidote-sericite-quartz.

Sample 2665675 is an augen textured foliated granite, with K-feldspar megacrysts wrapped by a quartz-ribbon and altered mica fabric (Fig. 47c).



**Figure 46. Schematic log of drillhole PBD 30 based on logging by Coles et al. (1991) and author observations.** Brief summary of petrology descriptions are from Coles et al. (1991).

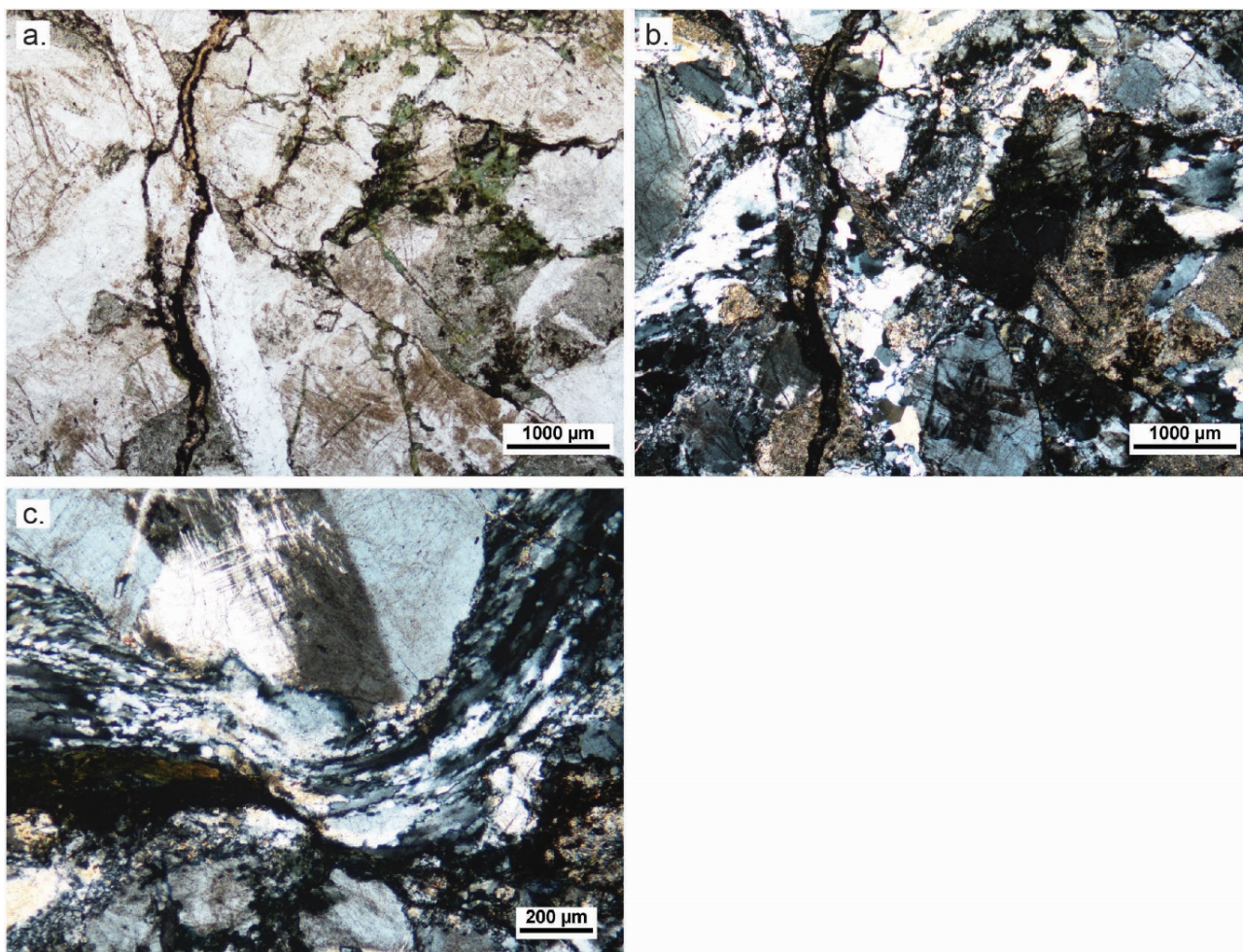


**Figure 47. Photographs of granitic rocks of drillhole PBD 30. (a) Granite, 177 m. (b) Medium to fine-grained granite, 153 m. (c) Sample 2665675, 120 m.**

## PETROGRAPHY

The sample is medium-grained and fractured K-feldspar (microcline) wrapped by recrystallised quartz ribbons and weakly to pervasively sericite-stained plagioclase (Fig. 48). There are disseminated flakes and clusters of chloritised biotite. Disseminated coarse leucoxenised opaques and disseminated euhedral apatite, minor zircons, rare metamict possible monazite.

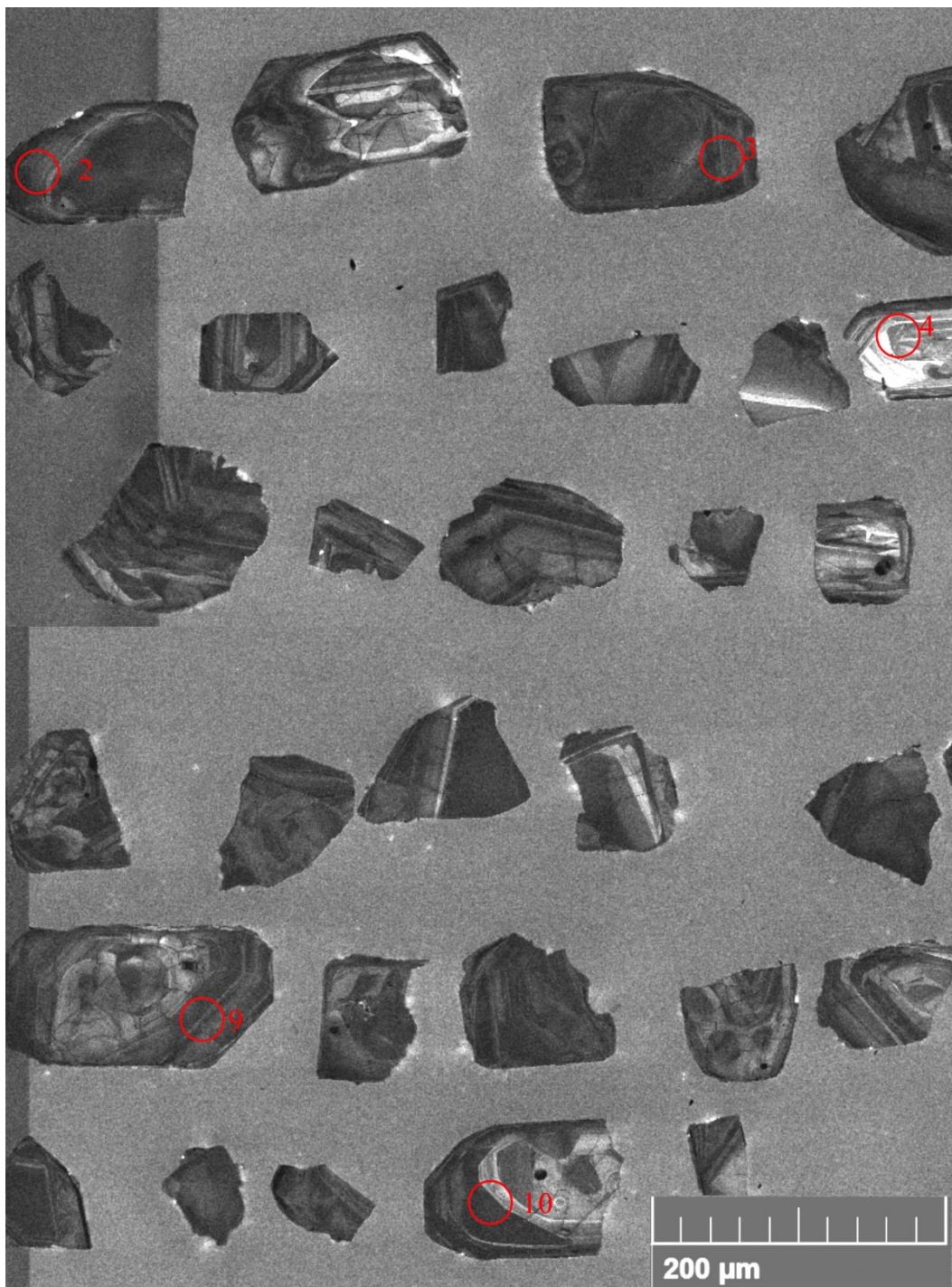




**Figure 48. Photomicrographs of sample 2665675. (a)** Transmitted plane polarised light. **(b)** Cross polars. **(c)** Detail of quartz ribbon wrapping K-feldspar megacryst. Cross polars.

## ZIRCON CHARACTERISTICS

Zircons from this sample are blocky grains with length to width ratios up to 3:1. The zircons have moderate CL response, with oscillatory zonation typical of igneous zircon (Fig. 49). In some examples, core-rim structure is evident, with the rims appearing to overgrow oscillatory zoned cores. The rims themselves are typically darker CL response, although they also have a zoned appearance, suggesting the structuring is a function of magma chamber zircon growth processes rather than metamorphic recrystallisation.

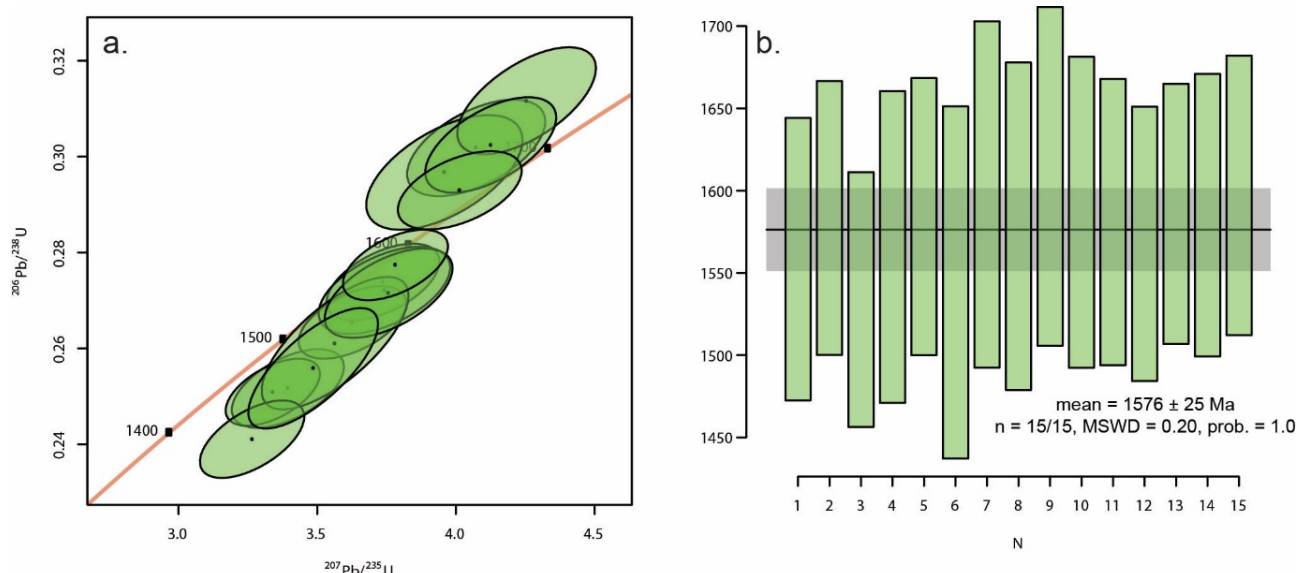


**Figure 49. Representative CL image of zircons from sample 2665675.** Circles indicate analytical sites.

## GEOCHRONOLOGICAL RESULTS

Fifteen zircons were analysed from sample 2665675. The data are all concordant or near concordant and cluster at c. 1580 Ma (Fig. 50a). A weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1576 \pm 25$  Ma ( $n = 15/15$ , MSWD = 0.20, prob. = 1.0; Fig. 50b) can be calculated from the data. This age is interpreted to be the timing of magmatic crystallisation of the sample, suggesting this granite is part of the Hiltaba Suite. Specifically, given the deformation fabric evident in the sample, the rock is similar to the Tickera Granite (see Conor, 1995; Brotodewo et al., 2018).





**Figure 50. Geochronology results for sample 2665675. (a) Concordia diagram. (b) Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation.**

## 2665668, granite, drillhole KD 10, 187.8–189 m

### SAMPLE INFORMATION

|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 2665668                                                                         |
| Collector:             | Zhao, Y                                                                         |
| Stratigraphic Unit:    | Hiltaba Suite                                                                   |
| Location Lat-Long:     | -33.691651 137.81729                                                            |
| Location:              | Drillhole KD 10, 187.8–189 m                                                    |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | 1556 ± 25 Ma                                                                    |
| Age type:              | Magmatic crystallisation age                                                    |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

### BACKGROUND

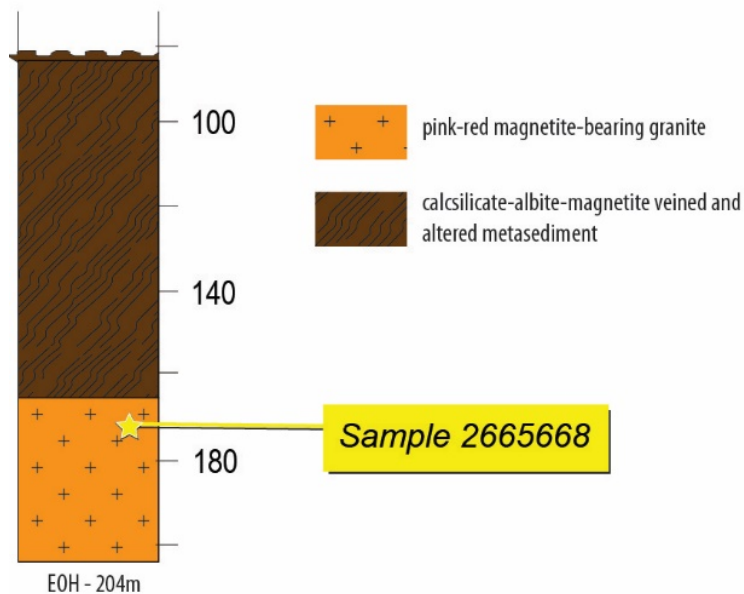
Drillhole KD 10 was drilled by Phelps Dodge as part of a program in the area known as the Katinka project (Drummond et al., 2000). This exploration program targeted Roxby Downs style and Ernest Henry style copper-gold mineralisation in an area of intensely magnetic, concealed metasedimentary and intrusive igneous basement terrain in the northern Yorke Peninsula. Detailed aeromagnetic and ground gravity surveys were carried out to define a large coincident magnetic/gravity anomaly which extends mainly offshore in this region. Drilling as part of this program located minor chalcopyrite mineralisation as coarse-grains with molybdenite in pegmatitic phases within granite, in quartz-tourmaline-chlorite veins in aplitic dykes, as disseminations and veinlets in calcsilicate-magnetite-albite-calcite metasomatite and associated with vein fill, breccia matrix-fill and wall rock assemblages dominated by quartz, hematite, pyrite, chalcopyrite, chalcocite, chlorite, calcite and/or Kfeldspar(?) and/or tourmaline. Highest grades of Cu and Au mineralisation were encountered in drillholes KD 11 and KD 16 in low-temperature veins and breccias associated with quartz, hematite and chlorite alteration. This mineralisation post-dates the high-temperature, calcsilicate-magnetite-albite-carbonate metasomatic alteration.

Drillhole KD 10 was on a broad, low-magnitude magnetic anomaly and intersected weak calcsilicate-albite-magnetite veined and altered metasedimentary rock intruded by pink-red magnetite-bearing granite (Figs 51, 52a).

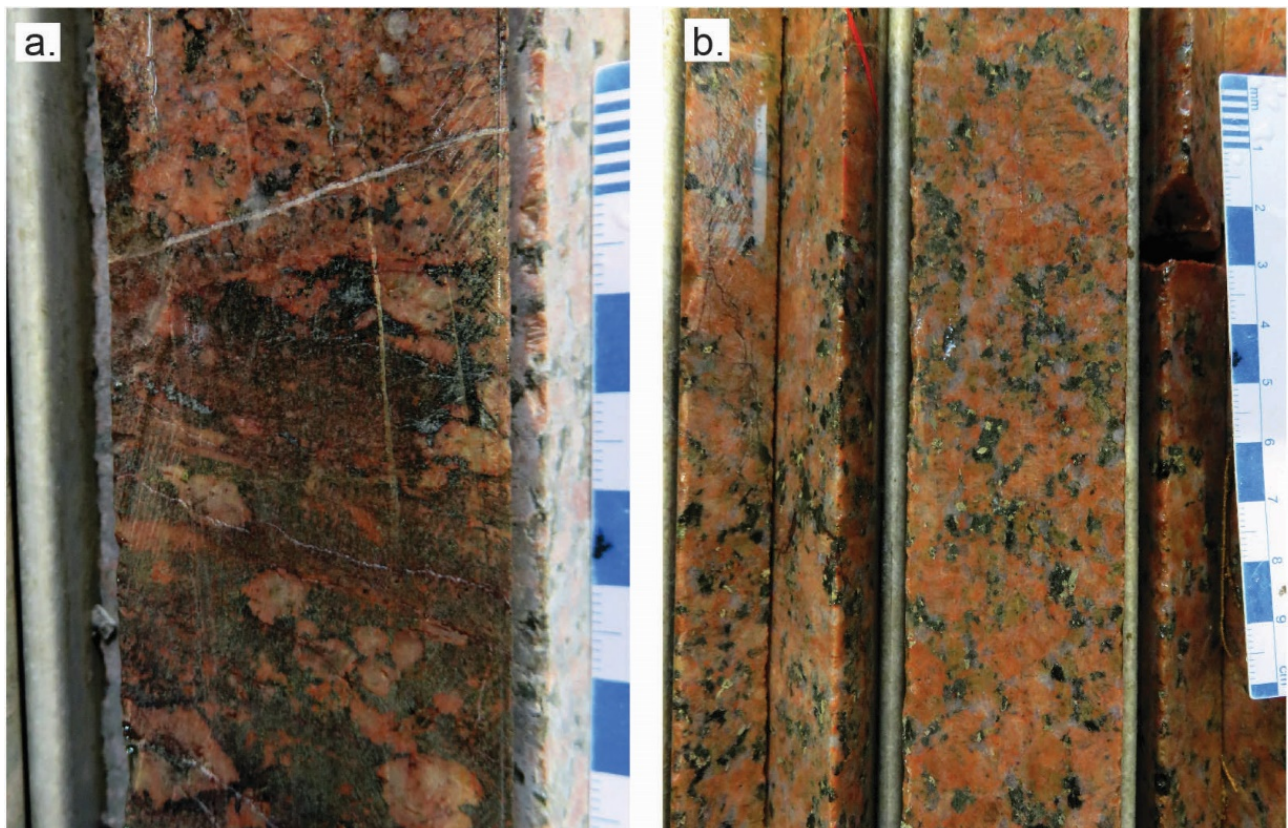


Sample 2665668 is representative of the granite in this drillhole and is a medium- to coarse-grained, red-coloured, biotite-bearing granite (Fig. 52b).

## KD 10



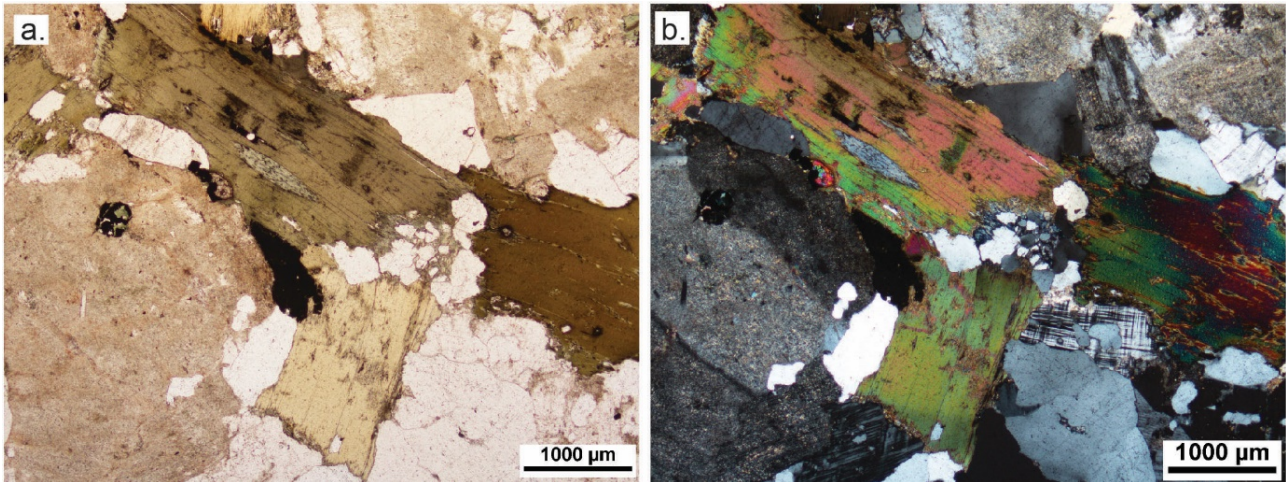
**Figure 51. Schematic log of drillhole KD 10 based on logging by Drummond et al. (2000) and author observations.**



**Figure 52. Photographs of rocks of drillhole KD 10. (a)** Contact between metasomatised metasedimentary rock, displaying amphibole- feldspar-rich alteration, and medium-grained pink granite phase (top portion of photo), 150 m. **(b)** Sample 2665668, coarse grained granite, 189 m.

## PETROGRAPHY

The sample is a coarse-grained granite comprising K-feldspar, quartz and plagioclase with randomly oriented biotite flakes (Fig. 53). The K-feldspar is perthitic microcline and variably altered. Plagioclase is variably sericite- and hematite-altered. Quartz shows weak undulose extinction and is intergrown with the anhedral feldspars. The biotite is green coloured and is weakly altered to chlorite along the margins of the grains. Accessory minerals include opaques, including magnetite, along with zircon, monazite and possible allanite. Approximate mineral abundance is quartz 35%; K-feldspar 40%; plagioclase 20%; biotite 4%; oxides 1%.

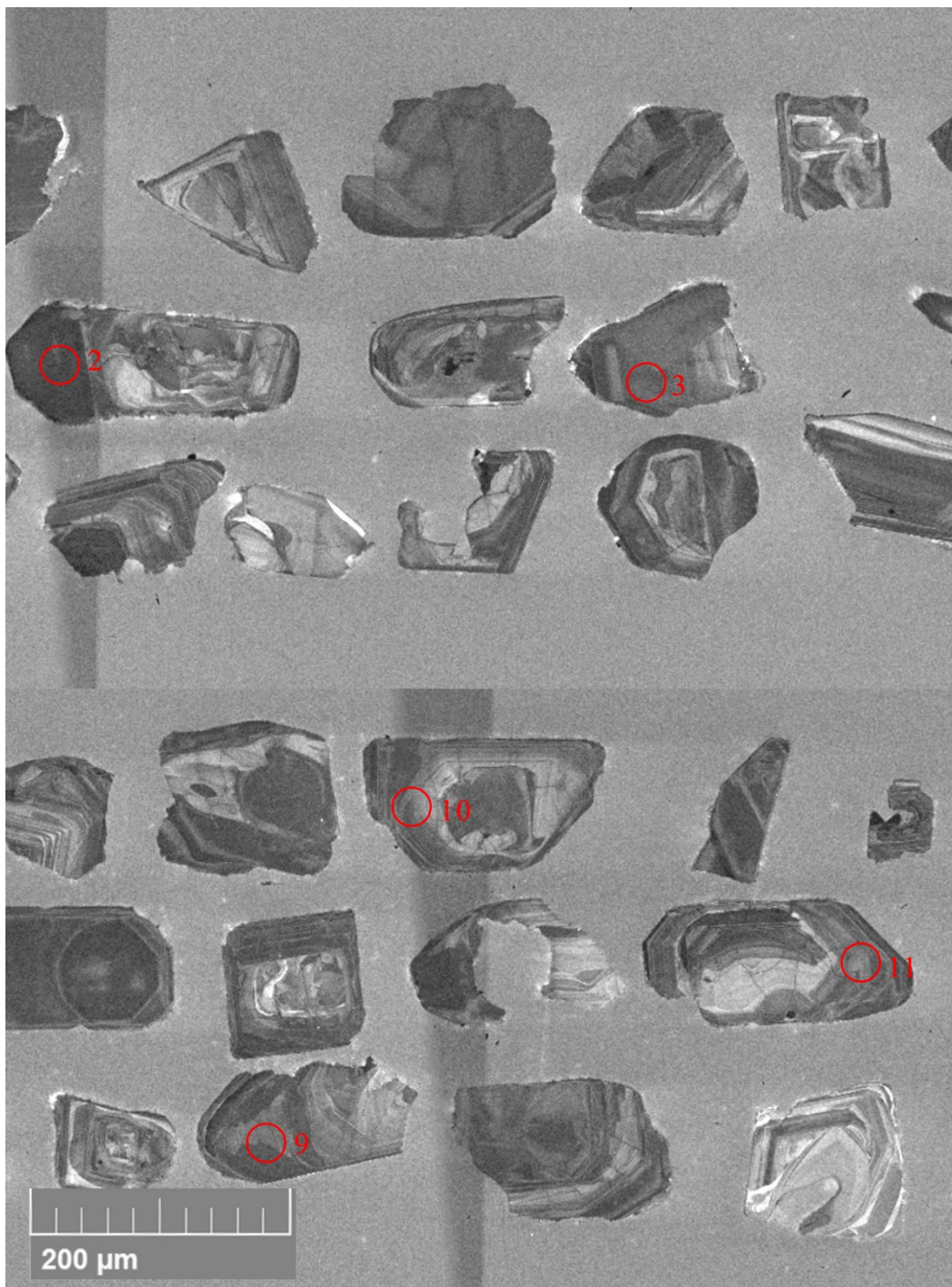


**Figure 53. Photomicrographs of sample 2665668. (a)** Transmitted plane polarised light.  
**(b)** Cross polars.

## ZIRCON CHARACTERISTICS

Zircons from this sample are variably elongate and fractured, with length to width ratios up to 4:1. The zircons have complex zonation patterns, with many grains appearing to have complex core-rim structures (Fig. 54). In some instances the core zones have dark CL response and in some instances the rim structure appears to be broadly concordant with the zonation in the core region. The oscillatory zonation is typical of igneous zircon.



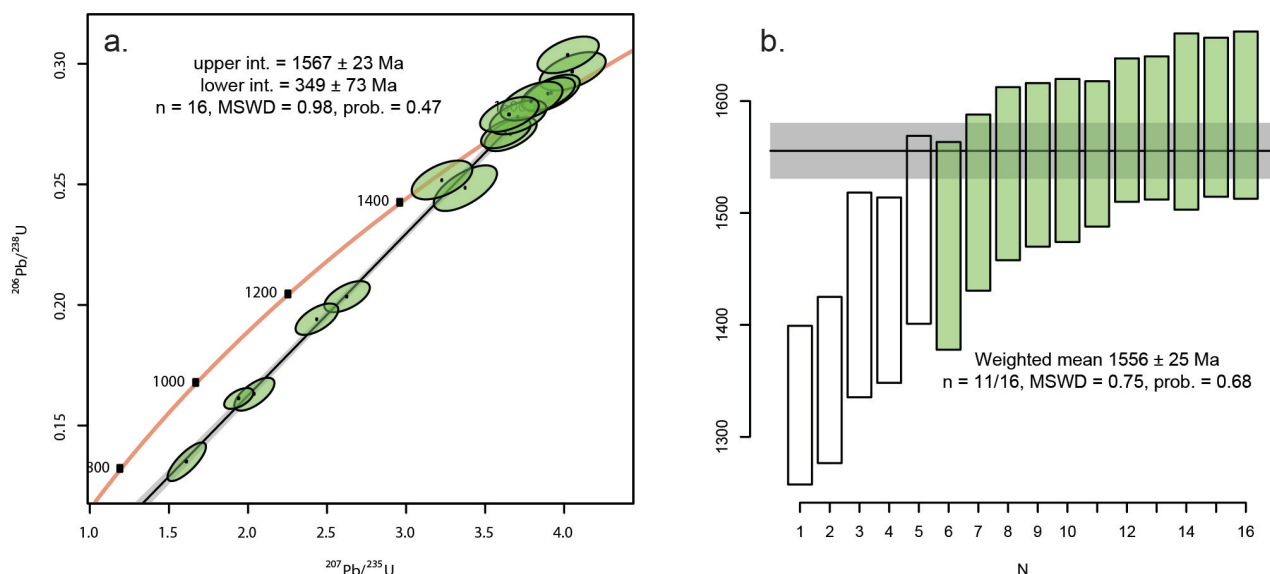


**Figure 54. Representative CL image of zircons from sample 2665675.** Circles indicate analytical sites.

## GEOCHRONOLOGICAL RESULTS

Sixteen zircons were analysed from sample 2665668, with the analyses showing a variation in concordance (Fig. 55a). A discordia line through all of the analyses yields an upper intercept age of  $1567 \pm 23$  Ma (MSWD = 0.98, prob. = 0.47). Pooling the 11 oldest analyses (< 5% discordant) results in a simple population with a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1556 \pm 25$  Ma (MSWD = 0.75, probability = 0.68; Fig. 55b), which provides a conservative estimate of the timing of emplacement of the granite in drillhole KD 10.





**Figure 55. Geochronology results for sample 2665668. (a) Concordia diagram. (b) Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation.**

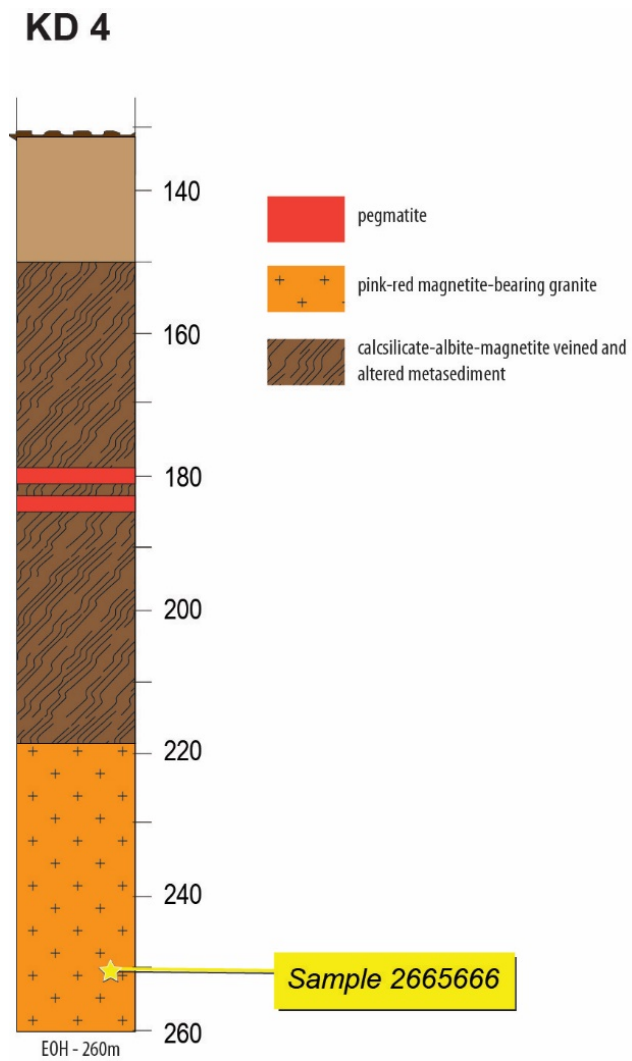
## 2665666, granite, drillhole KD 4, 250.25–251.6 m

### SAMPLE INFORMATION

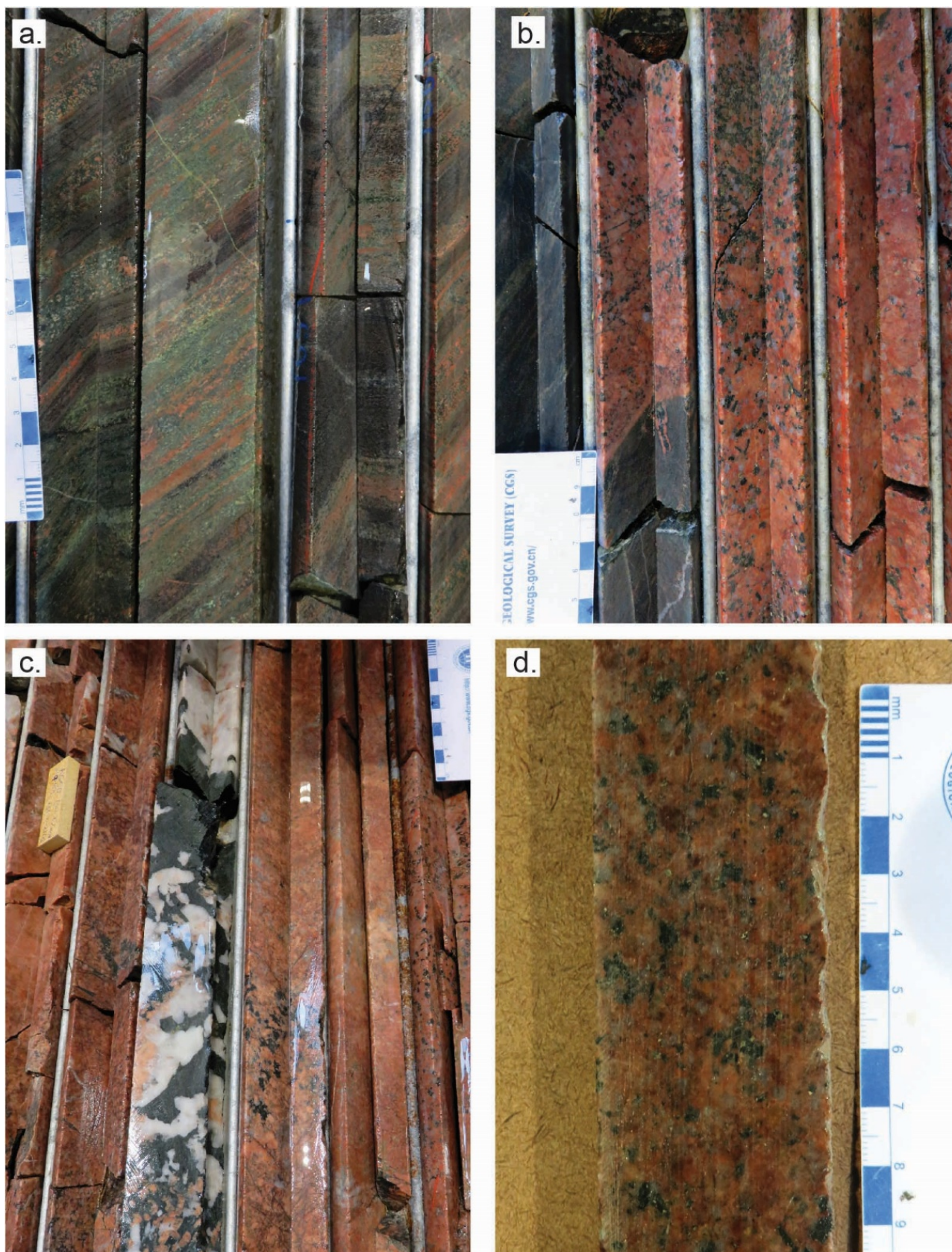
|                        |                                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Sample Number:         | 2665666                                                                         |
| Collector:             | Zhao, Y                                                                         |
| Stratigraphic Unit:    | Hiltaba Suite                                                                   |
| Location Lat-Long:     | -33.698577 137.816772                                                           |
| Location:              | Drillhole KD 4, 250.25–251.6 m                                                  |
| Machine:               | Thermo X series 2 ICP-MS, Shandong Bureau of China Metallurgical Geology Bureau |
| Interpreted age:       | $1546 \pm 19$ Ma                                                                |
| Age type:              | Magmatic crystallisation age                                                    |
| Age calculation method | Weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age                             |

### BACKGROUND

Drillhole KD 4 was drilled as part of the Katinka project and intersected calcsilicate-albite-magnetite veined and altered metasedimentary rock intruded by pink-red magnetite-bearing granite (Figs 56, 57a, b; Drummond et al., 2000). The granite shows weak composition zoning and contains pegmatite phases comprising quartz-albite-K feldspar-hornblende/actinolite-calcite (Fig. 57c). Chalcopyrite, molybdenite, pyrite or magnetite are reported from selected pegmatite intervals (Drummond et al., 2000). A sample of pink-coloured, medium-grained granite was taken from this drillhole (Fig. 57d).



**Figure 56. Schematic log of drillhole KD 4 based on logging by Drummond et al. (2000) and author observations.**

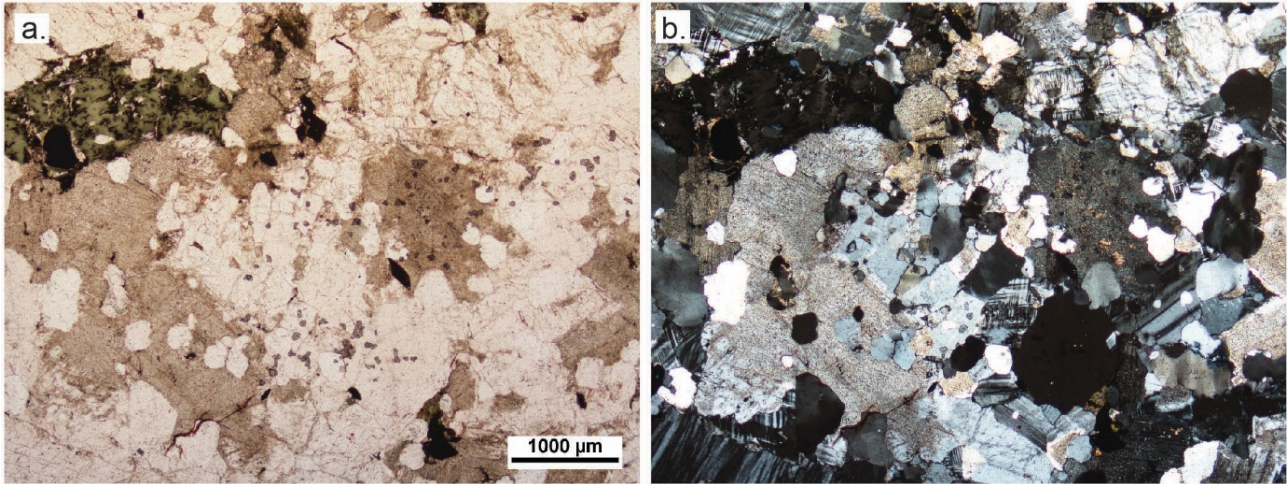


**Figure 57. Photographs of rocks of drillhole KD 4. (a)** Layered, metasomatised metasedimentary rock, displaying amphibole- feldspar-rich alteration, 164.2 m. **(b)** Contact between granite and metasedimentary rock of drillhole, 218 m. **(c)** Example of amphibole-rich coarse pegmatite within the granite of drillhole KD 10, 235 m. **(d)** Sample 2665666, granite, 250 m.



## PETROGRAPHY

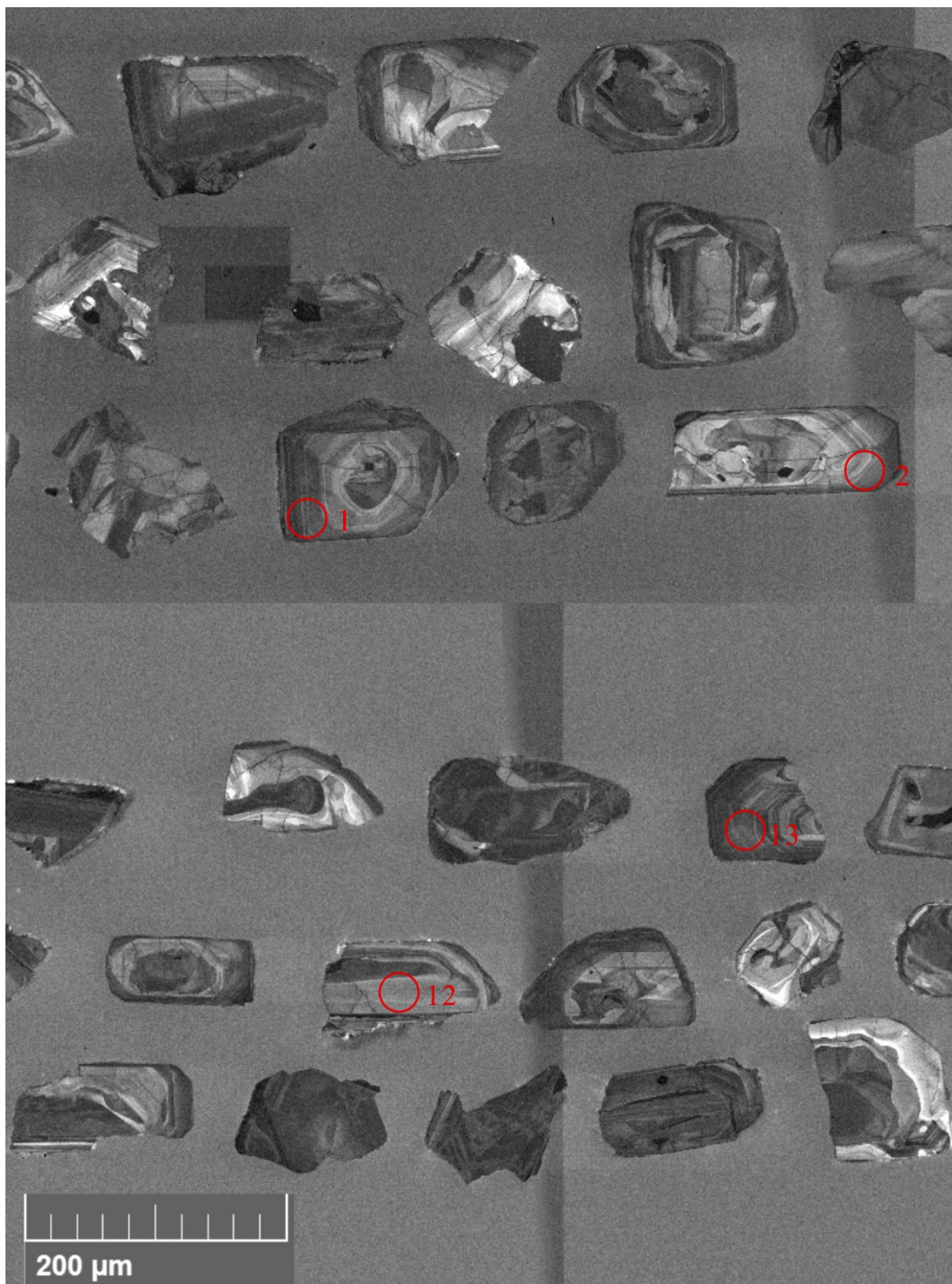
The sample is an extensively altered medium-grained granite. Quartz occurs as a framework mineral and as inclusions within feldspars (Fig. 58). Undulose extinction is visible in some quartz crystals. Plagioclase is extensively replaced by sericite. K-feldspar is less altered than the plagioclase, and occurs as coarse- to medium-grained polygonal crystals. Clots of biotite are completely replaced by green chlorite. Opaque species occur interstitially to the framework silicate minerals, and likely include magnetite. The reddish colour suggests hematite dusting throughout.



**Figure 58. Photomicrographs of sample 2665666. (a)** Transmitted plane polarised light.  
**(b)** Cross polars.

## ZIRCON CHARACTERISTICS

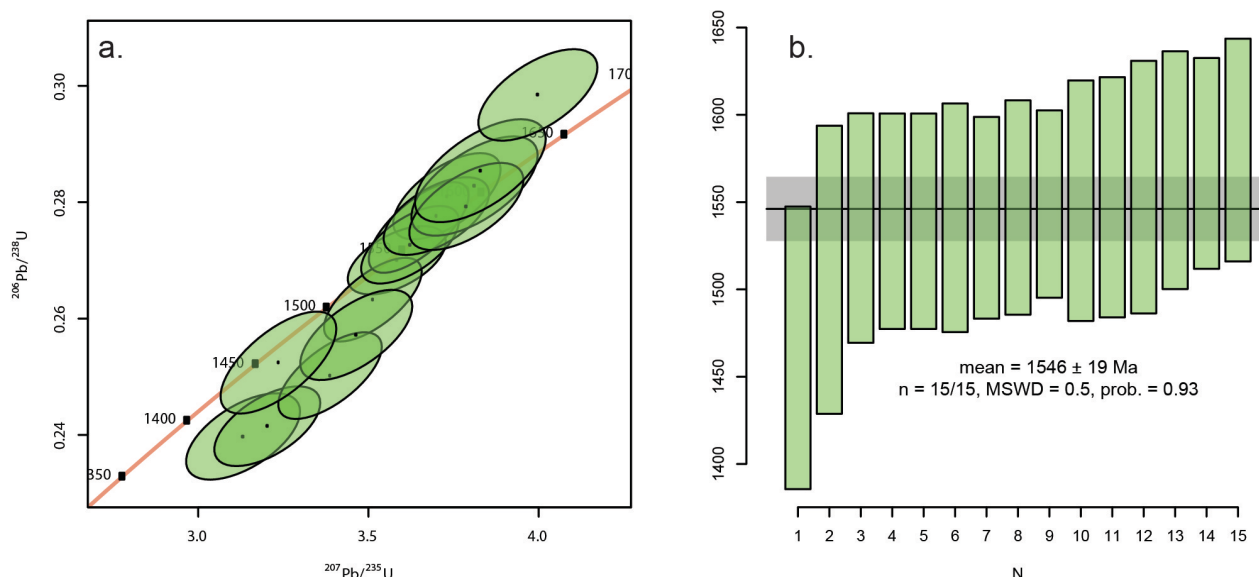
Zircons from this sample are blocky, variably elongate and fractured, and having length to width ratios up to 4:1. The zircons have complex zonation patterns, with many grains appearing to have inclusions (apatite?) and complex core-rim structures (Fig. 59). In some instances the core zones have dark CL response and in some instances the rim structure appears to be resorption feature on earlier core, and in others the zonation is broadly concordant with the banding or zonation in the core region. The oscillatory zonation is typical of igneous zircon.



**Figure 59. Representative CL image of zircons from sample 2665666. Circles indicate analytical sites.**

## GEOCHRONOLOGICAL RESULTS

Fifteen zircons were analysed from sample 2665666 and the data are concordant to near concordant (Fig. 60). The data cluster at around 1550 Ma, and all data can be pooled to yield a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of a weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1546 \pm 19$  Ma (MSWD = 0.5, probability = 0.93, n = 15).



**Figure 60. Geochronology results for sample 2665666. (a) Concordia diagram. (b) Weighted mean  $^{207}\text{Pb}/^{206}\text{Pb}$  age calculation.**

## ACKNOWLEDGEMENTS

This work was undertaken under the auspices of a Memorandum of Understanding between the China Geological Survey, Nanjing Key Center, and Geological Survey of South Australia. Dr Baohong Hou (GSSA) and Professor Yao (China Geological Survey, Nanjing) are thanked for their leadership in developing this collaboration. Liz Jagodzinski provided a thorough review.

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# APPENDIXES

## APPENDIX 1. SAMPLE SPREADSHEETS

Excel spreadsheets for the 14 samples in the text. Click the sheet name to access these attachments.

[2665664\\_AR.xls](#)

[2665666\\_AR.xls](#)

[2665668\\_AR.xls](#)

[2665675\\_AR.xls](#)

[2665676\\_AR.xls](#)

[3037021\\_SA02\\_AR.xls](#)

[3037022\\_SA05\\_AR.xls](#)

[3037023\\_SA06\\_AR.xls](#)

[3037024\\_SA01\\_AR.xls](#)

[3037025\\_SA03\\_AR.xls](#)

[3037026\\_SA07\\_AR.xls](#)

[3037027\\_SA08\\_AR.xls](#)

[3037028\\_SA09\\_AR.xls](#)

[3037029\\_SA04\\_AR.xls](#)

## APPENDIX 2. WHOLE ROCK GEOCHEMISTRY AND Sr-Nd ISOTOPIC DATA FOR SAMPLES

### Analytical methods

#### WHOLE ROCK GEOCHEMISTRY

The analysis of major elements in the whole rock was completed at the National Geological Experiment and Testing Center. The analysis adopts lithium tetraborate glass X-ray fluorescence spectrometer (XRF) test. The specific process is: weigh about 1 g sample and place it in a muffle furnace at 900 °C for 1.5 hours. After completion, take it out and put it in a desiccator. After cooling, weigh the mass, and calculate the loss on ignition, then weigh about 0.6 g of the residue from the previous step, and weigh about 8 times the mass of the residue of lithium tetraborate flux, mix well, weigh about 8 times the mass of the residue of lithium tetraborate flux, mix it evenly, pour it into a platinum crucible and add appropriate amount of release agent lithium bromide and oxidant lithium nitrate, and place it at 1200 °C for high temperature melting. After the melting is completed, take it out and pour it into a platinum abrasive tool and cool it into a glass sheet. Test on the machine, and the analysis accuracy is better than 5%.

The analysis of trace elements was undertaken using a Perkin-Elmer ELAN 300D inductively coupled plasma mass spectrometer (ICP-MS) at the National Geological Experiment and Testing Center. The sample pretreatment process is as follows: accurately weigh 25 mg of 200 mesh sample and add it to a Teflon tank, add 1 mL HF and 0.5 mL HNO<sub>3</sub>, cover and put it in a stainless steel jacket, place it in an oven and decompose at 190 °C for 48 hours. Take it out and evaporate to dryness on a hot plate, add 1 mL HNO<sub>3</sub> and evaporate to dryness and repeat once. Add 2 mL 1:1 HNO<sub>3</sub> distilled water and put it in the oven at 120 °C to dissolve the residue for 8 hours. After completion, take it out and cool, and dilute to 20 mL to be tested. National standard samples GSR-1 and GSR-3 are used for analysis quality control, and the analysis accuracy is better than 10%.

## SR-ND ISOTOPIC DATA

Sr-Nd analyses was undertaken using about 250 mg of each sample, which was weighed into a 7 ml round bottom Teflon capsule followed by 0.5 mL of concentrated HNO<sub>3</sub> and 1.5 mL of concentrated HF. The capsules were capped and heat in bake oven at 190 °C for 48 hours. Following complete dissolution, the capsule was opened and then heated on a hotplate at 160 °C to evaporate to dryness. The capsule was again sealed and heat at 150 °C for 6 hours after 3 mL 50% concentrated HNO<sub>3</sub> was added the residue. After cooling, the solution was dilution to 25 ml using ultrapure water. After chemical purification by Sr-spec and LN resins respectively, the Sr-Nd isotopic compositions were measured using Neptune Plus MC-ICP-MS. <sup>87</sup>Sr/<sup>86</sup>Sr and <sup>143</sup>Nd/<sup>144</sup>Nd ratios were normalised to <sup>88</sup>Sr/<sup>86</sup>Sr = 8.373209 and <sup>146</sup>Nd/<sup>144</sup>Nd = 0.7218 based on exponential law. During the period of date acquisition, standard solution yielded results of <sup>87</sup>Sr/<sup>86</sup>Sr = 0.710262 ± 15 (2SD, n=12) for NBS987 and <sup>143</sup>Nd/<sup>144</sup>Nd = 0.512110 ± 13 (2SD, n=10) for JNdi-1. In addition, the USGS reference materials BCR-2 and BHVO-2 yielded the results consistent well with the published values.

## Results

Whole rock major element data are given in Table 1, trace element data are given in Table 2 and rare earth element data are given in Table 3.

**Table 1. Major element whole rock geochemistry.**

| Sample  | Al <sub>2</sub> O <sub>3</sub><br>% | CaO<br>% | Fe <sub>2</sub> O <sub>3</sub><br>% | K <sub>2</sub> O<br>% | MgO<br>% | MnO<br>% | Na <sub>2</sub> O<br>% | P <sub>2</sub> O <sub>5</sub><br>% | TiO <sub>2</sub><br>% | SiO <sub>2</sub><br>% | LOI<br>% | SUM<br>% |
|---------|-------------------------------------|----------|-------------------------------------|-----------------------|----------|----------|------------------------|------------------------------------|-----------------------|-----------------------|----------|----------|
| 3037024 | 13.81                               | 9.28     | 13.23                               | 2.77                  | 6.69     | 0.18     | 1.70                   | 0.15                               | 1.27                  | 48.11                 | 2.05     | 99.23    |
| 3037021 | 13.55                               | 0.56     | 3.22                                | 5.05                  | 1.00     | 0.03     | 2.68                   | 0.12                               | 0.59                  | 72.18                 | 1.03     | 100.01   |
| 3037025 | 13.23                               | 1.13     | 2.43                                | 0.59                  | 0.07     | 0.00     | 5.88                   | 0.14                               | 0.71                  | 75.25                 | 0.56     | 100.00   |
| 3037029 | 12.61                               | 1.84     | 3.79                                | 4.60                  | 0.66     | 0.04     | 2.53                   | 0.09                               | 0.41                  | 73.14                 | 0.22     | 99.91    |
| 3037022 | 12.64                               | 0.21     | 2.09                                | 6.55                  | 0.56     | 0.01     | 1.62                   | 0.12                               | 0.34                  | 75.07                 | 0.72     | 99.93    |
| 3037023 | 13.53                               | 0.16     | 2.53                                | 6.59                  | 0.64     | 0.03     | 1.97                   | 0.10                               | 0.36                  | 72.19                 | 1.01     | 99.11    |
| 3037026 | 9.92                                | 3.63     | 1.92                                | 1.16                  | 0.70     | 0.02     | 3.51                   | 0.07                               | 0.29                  | 78.28                 | 0.51     | 100.01   |
| 3037027 | 5.90                                | 17.33    | 13.77                               | 0.06                  | 9.00     | 0.12     | 0.41                   | 0.08                               | 0.24                  | 51.58                 | 0.69     | 99.19    |
| 3037028 | 10.39                               | 14.30    | 9.25                                | 0.30                  | 6.55     | 0.09     | 3.53                   | 0.14                               | 0.36                  | 53.72                 | 1.20     | 99.84    |



**Table 2. Trace element geochemistry.**

| Sample  | Li   | Be   | Sc   | Ti   | V    | Cr   | Mn   | Co   | Ni   | Cu   | Zn   | Ga   | As   | Se   | Rb   | Sr   | Y    | Zr   | Nb   | Mo   | Sn   | Cs   | Ba   | Hf   | Ta   | Pb   | Th   | U    |
|---------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 3037024 | 42.4 | 0.95 | 39.9 | 7255 | 322  | 187  | 1393 | 47.5 | 86.3 | 159  | 66.0 | 17.3 | 2.60 | 0.65 | 255  | 121  | 25.0 | 83.6 | 5.49 | 0.43 | 1.12 | 4.46 | 309  | 2.29 | 0.36 | 2.02 | 1.81 | 0.54 |
| 3037021 | 11.6 | 2.45 | 10.5 | 3336 | 45.6 | 24.6 | 198  | 5.71 | 10.3 | 19.0 | 8.56 | 18.2 | 1.52 | 1.04 | 208  | 59.2 | 30.8 | 142  | 22.6 | 0.11 | 3.61 | 1.18 | 561  | 3.94 | 1.38 | 2.77 | 18.8 | 2.54 |
| 3037025 | 1.92 | 2.83 | 9.59 | 3915 | 21.7 | 5.22 | 27.9 | 0.98 | 1.06 | 0.51 | 1.14 | 15.1 | 3.18 | 1.90 | 23.3 | 238  | 56.7 | 492  | 37.6 | 0.43 | 4.38 | 1.01 | 149  | 12.6 | 2.52 | 4.07 | 22.8 | 4.91 |
| 3037029 | 36.1 | 3.10 | 7.83 | 2376 | 27.3 | 9.23 | 344  | 6.33 | 4.92 | 9.49 | 58.5 | 21.9 | 2.26 | 1.23 | 250  | 108  | 35.8 | 139  | 11.5 | 0.35 | 3.94 | 7.41 | 684  | 3.74 | 0.95 | 28.4 | 24.5 | 3.53 |
| 3037022 | 7.28 | 2.15 | 5.73 | 1924 | 27.8 | 12.8 | 105  | 4.15 | 5.57 | 8.68 | 3.80 | 14.9 | 1.33 | 0.91 | 208  | 66.0 | 27.6 | 83.9 | 12.8 | 0.20 | 2.55 | 0.67 | 670  | 2.34 | 0.79 | 3.38 | 12.3 | 1.87 |
| 3037023 | 7.27 | 1.53 | 7.16 | 2098 | 31.3 | 14.1 | 197  | 6.04 | 8.17 | 2.60 | 5.64 | 14.9 | 1.63 | 0.55 | 212  | 71.2 | 13.3 | 92.2 | 13.6 | 0.30 | 2.51 | 0.85 | 730  | 2.48 | 0.92 | 4.24 | 13.4 | 2.07 |
| 3037026 | 0.20 | 4.73 | 1.97 | 1696 | 15.6 | 7.03 | 127  | 1.85 | 1.12 | 25.4 | 2.18 | 9.50 | 1.50 | 0.66 | 38.2 | 80.4 | 24.0 | 110  | 10.7 | 0.28 | 11.8 | 0.21 | 201  | 2.99 | 0.71 | 1.96 | 3.44 | 3.63 |
| 3037027 | 14.6 | 21.5 | 24.7 | 1472 | 96.9 | 66.1 | 909  | 24.7 | 10.9 | 237  | 19.8 | 11.5 | 2.17 | 0.79 | 1.13 | 151  | 24.0 | 234  | 9.30 | 0.45 | 20.0 | 0.06 | 8.05 | 6.04 | 0.57 | 2.73 | 2.66 | 3.57 |
| 3037028 | 12.1 | 14.9 | 14.2 | 2148 | 63.5 | 33.7 | 655  | 29.9 | 11.0 | 75.4 | 13.7 | 11.7 | 3.96 | 0.85 | 10.0 | 109  | 31.4 | 142  | 13.6 | 1.87 | 18.4 | 0.22 | 22.2 | 3.84 | 1.08 | 3.56 | 4.29 | 2.77 |
| 3037024 | 41.5 | 0.91 | 39.6 | 7263 | 323  | 192  | 1385 | 47.9 | 89.1 | 159  | 70.9 | 17.7 | 2.46 | 0.61 | 254  | 118  | 25.0 | 82.4 | 5.44 | 0.47 | 1.12 | 4.45 | 304  | 2.26 | 0.35 | 2.03 | 1.79 | 0.54 |

**Table 3. Rare earth element data.**

| Sample  | La   | Ce   | Pr   | Nd   | Sm   | Eu   | Gd   | Tb   | Dy   | Ho   | Er   | Tm   | Yb   | Lu   |
|---------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 3037024 | 9.50 | 21.4 | 2.79 | 12.7 | 3.23 | 0.96 | 3.74 | 0.67 | 4.34 | 0.91 | 2.61 | 0.39 | 2.43 | 0.37 |
| 3037021 | 38.5 | 82.1 | 9.18 | 34.8 | 6.27 | 0.91 | 5.23 | 0.88 | 5.43 | 1.12 | 3.24 | 0.49 | 3.12 | 0.45 |
| 3037025 | 55.1 | 114  | 12.6 | 46.4 | 8.78 | 1.60 | 8.08 | 1.49 | 9.85 | 2.07 | 6.21 | 0.97 | 6.25 | 0.95 |
| 3037029 | 63.0 | 124  | 13.3 | 47.3 | 7.45 | 0.96 | 6.07 | 1.01 | 5.99 | 1.23 | 3.47 | 0.50 | 3.01 | 0.44 |
| 3037022 | 31.7 | 65.0 | 7.30 | 26.4 | 5.25 | 1.02 | 4.82 | 0.85 | 5.27 | 1.05 | 2.95 | 0.43 | 2.69 | 0.38 |
| 3037023 | 22.5 | 48.9 | 5.19 | 18.8 | 3.57 | 0.61 | 2.78 | 0.44 | 2.57 | 0.51 | 1.50 | 0.23 | 1.55 | 0.24 |
| 3037026 | 4.18 | 21.7 | 2.53 | 12.9 | 3.99 | 0.84 | 3.84 | 0.68 | 4.18 | 0.80 | 2.22 | 0.32 | 1.94 | 0.24 |
| 3037027 | 6.97 | 19.7 | 3.30 | 16.6 | 4.94 | 1.16 | 4.40 | 0.72 | 4.28 | 0.81 | 2.20 | 0.34 | 2.19 | 0.35 |
| 3037028 | 9.23 | 29.0 | 4.80 | 23.8 | 6.74 | 1.43 | 5.92 | 0.98 | 5.80 | 1.09 | 2.94 | 0.45 | 2.77 | 0.40 |
| 3037024 | 9.33 | 21.1 | 2.76 | 12.7 | 3.28 | 0.97 | 3.76 | 0.66 | 4.40 | 0.91 | 2.60 | 0.39 | 2.46 | 0.37 |

## Whole rock Sr-Nd isotopic data

Rb-Sr and Sm-Nd ratios are summarised in Table 4 and Table 5 respectively.

**Table 4. Summary of Rb-Sr data from samples in this report.**

| Sample number | Location        | Description                      | t (Ma) | Rb (ppm) | Sr (ppm) | <sup>87</sup> Rb/ <sup>86</sup> Sr | <sup>87</sup> Sr/ <sup>86</sup> Sr | 2σ       | ISr      |
|---------------|-----------------|----------------------------------|--------|----------|----------|------------------------------------|------------------------------------|----------|----------|
| 3037024       | Port Victoria   | Metabasalt                       | 1740   | 254.5963 | 120.6897 | 6.104059                           | 0.82148                            | 0.000004 | 0.668782 |
| 3037021       | Houghton Inlier | Augen Gneiss                     | 1690   | 208.3106 | 59.2309  | 10.17654                           | 0.891665                           | 0.000006 | 0.644495 |
| 3037025       | Port Victoria   | Felsic Volcanic                  | 1780   | 23.29378 | 238.2631 | 0.282892                           | 0.717125                           | 0.000006 | 0.709883 |
| 3037029       | Berry Bay       | Augen Gneiss                     | 1840   | 249.8091 | 108.0299 | 6.69116                            | 0.862751                           | 0.000007 | 0.68562  |
| 3037022       | Houghton Inlier | Augen Gneiss                     | 1710   | 208.2196 | 65.98715 | 9.130599                           | 0.881133                           | 0.000015 | 0.65671  |
| 3037023       | Houghton Inlier | Altered Hematite<br>Augen Gneiss | 1710   | 211.8024 | 71.21939 | 8.605371                           | 0.898934                           | 0.000008 | 0.687421 |
| 3037026       | Quarry          | Metasomatite                     | 1865   | 38.17051 | 80.44984 | 1.372903                           | 0.737937                           | 0.000006 | 0.701093 |
| 3037027       | Quarry          | Metasomatite                     | 1860   | 1.128571 | 151.3531 | 0.021576                           | 0.719595                           | 0.000006 | 0.719018 |
| 3037028       | Quarry          | Metasomatite                     | 1770   | 10.04496 | 109.1252 | 0.266355                           | 0.724763                           | 0.000006 | 0.717984 |

**Table 5. Summary of Sm-Nd data from samples in this report.**

| Sample number | t (Ma) | Sm (ppm) | Nd (ppm) | <sup>147</sup> Sm/ <sup>144</sup> Nd | <sup>143</sup> Nd/ <sup>144</sup> Nd | 2σ       | Sm/Nd    | INd      | εNd(0)   | εNd(t)   | 2σ       | TDM  | TDMC |
|---------------|--------|----------|----------|--------------------------------------|--------------------------------------|----------|----------|----------|----------|----------|----------|------|------|
| 3037024       | 1740   | 3.234616 | 12.69371 | 0.153964                             | 0.511873                             | 0.000008 | 0.25482  | 0.510111 | -14.9228 | -5.4057  | 0.078372 | 3242 | 2679 |
| 3037021       | 1690   | 6.270502 | 34.81024 | 0.108838                             | 0.511529                             | 0.000009 | 0.180134 | 0.510319 | -21.6332 | -2.59587 | 0.088157 | 2349 | 2412 |
| 3037025       | 1780   | 8.782176 | 46.44662 | 0.114244                             | 0.511832                             | 0.00001  | 0.189081 | 0.510494 | -15.7226 | 3.125389 | 0.097975 | 2016 | 2026 |
| 3037029       | 1840   | 7.44956  | 47.31205 | 0.095136                             | 0.511349                             | 0.000011 | 0.157456 | 0.510197 | -25.1444 | -1.16473 | 0.107789 | 2308 | 2420 |
| 3037022       | 1710   | 5.245196 | 26.42027 | 0.119952                             | 0.511554                             | 0.000009 | 0.198529 | 0.510205 | -21.1455 | -4.32742 | 0.088162 | 2585 | 2568 |
| 3037023       | 1710   | 3.570035 | 18.7712  | 0.114912                             | 0.511564                             | 0.00001  | 0.190187 | 0.510272 | -20.9505 | -3.02093 | 0.097957 | 2439 | 2463 |
| 3037026       | 1865   | 3.994742 | 12.89562 | 0.187168                             | 0.512059                             | 0.000007 | 0.309775 | 0.509762 | -11.2945 | -9.05522 | 0.068597 | 6190 | 3073 |
| 3037027       | 1860   | 4.939897 | 16.63858 | 0.179385                             | 0.512186                             | 0.000008 | 0.296894 | 0.509991 | -8.81714 | -4.70543 | 0.078396 | 4253 | 2721 |
| 3037028       | 1770   | 6.741196 | 23.81388 | 0.171037                             | 0.512114                             | 0.00001  | 0.283078 | 0.510123 | -10.2216 | -4.41284 | 0.097972 | 3681 | 2624 |