Shrimp U–Pb dating of ignimbrites in the Pul Pul Rhyolite, Northern Territory

A cautionary tale

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Isotopic dating of volcanic rocks in sedimentary sequences has a wide variety of applications, as the data can provide direct numerical ages to complement stratigraphic, basin analysis, and timescale studies. The primary eruptive products of silicic volcanic centres are pyroclastic fall deposits (tuffs), pyroclastic flow deposits (ignimbrites), and small-volume rhyolite lavas. Ignimbrites are the most voluminous of these volcanic products. They are laterally extensive, have good preservation potential, and generally form the dominant component of ancient volcanic successions. For these reasons, they are likely to be a common target for the dating of volcanic complexes and stratigraphic sequences. However, of all the primary volcanic facies, ignimbrites present the most difficult dating prospect because they are the products of violent and explosive volcanic activity, and the pyroclastic flow commonly assimilates large volumes of country rock during eruption and deposition. It is important to be aware that geochemical and geochronological analyses of ignimbrites are therefore subject to considerable error because these xenoliths can introduce inheritance into the zircon population. Inheritance presents a widely recognised problem in U–Pb age-dating studies, as the crystallisation ages of complex zircon populations with polymodal age distributions can be difficult to resolve.

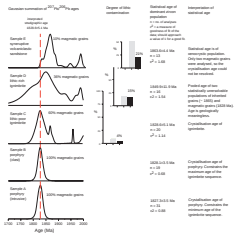

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Fig. 26. A summary of the data obtained for all samples analysed in this study. The left-hand column compares histograms of the $^{207}Pb/^{206}Pb$ ages obtained for each sample, and illustrates how lithic contamination increases the complexity of the zircon populations (only ages less than 2000 Ma are plotted).

Sample constraints for dating the Pul Pul Rhyolite

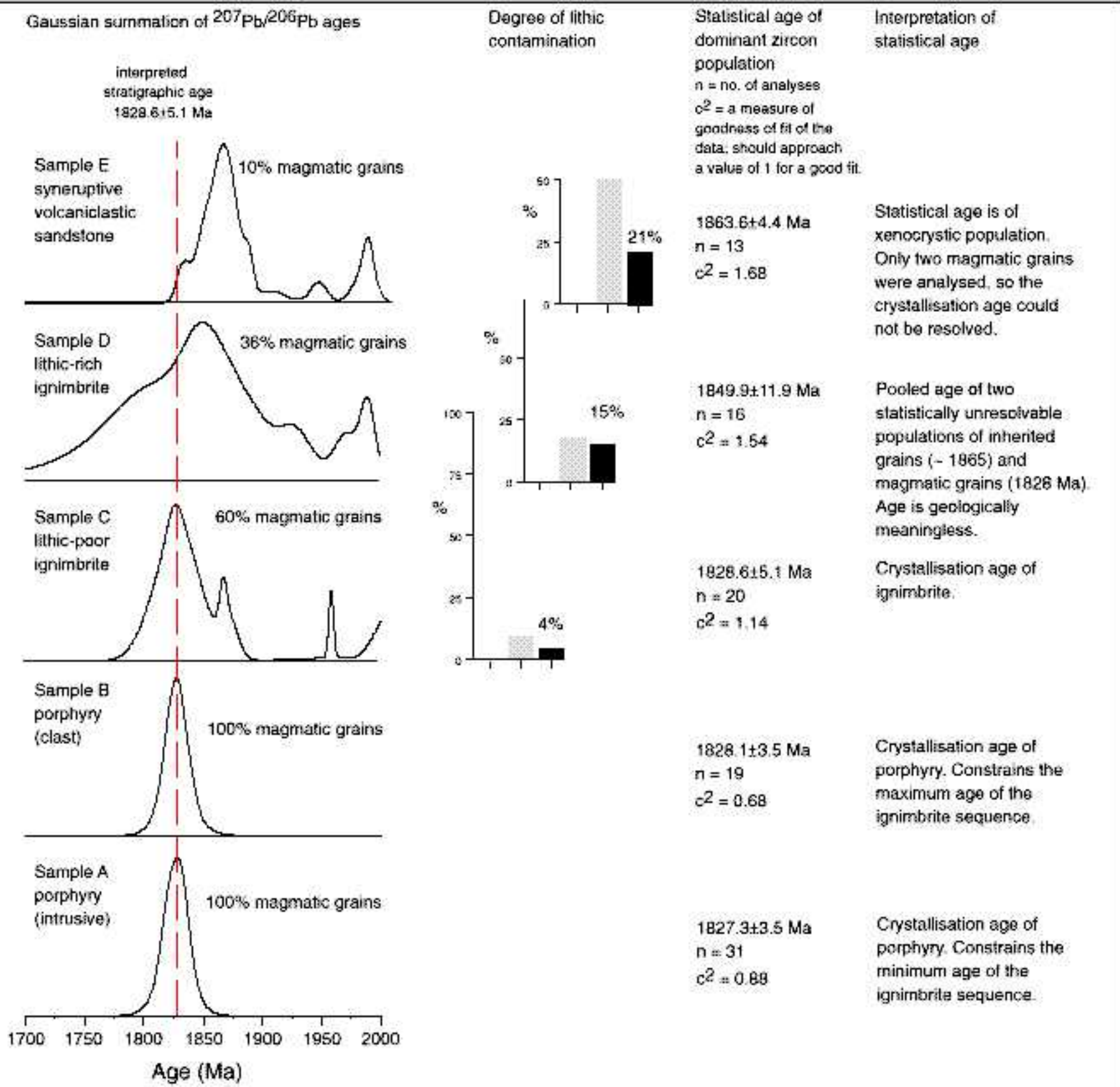
A geochronological study of the Pul Pul Rhyolite (Pine Creek Inlier, NT) highlights some of the problems that can be encountered in obtaining a stratigraphic age for a lithic-rich ignimbrite sequence. The Pul Pul Rhyolite is a volcanic formation of the El Sherana Group, which comprises a thick (830 m) sequence of ignimbrites and minor volcaniclastic rocks and intrusive rhyolite porphyries. The ignimbrites contain a high proportion of lithic contamination —including basalt, porphyry, sandstone, granite, chert, and metasedimentary basement clasts, most of which are potential sources of zircon contamination.

Three samples from the volcanic sequence containing varying degrees of lithic contamination were selected for U–Pb dating: lithic-poor (4% lithic constituents; sample C in Fig. 26) and lithic-rich ignimbrites (15% lithic constituents; sample D) and a syneruptive volcaniclastic rock (21% lithic constituents; sample E) were selected to determine the effect of xenolithic contamination on the zircon populations. In addition, two samples of quartz–feldspar porphyry were selected to provide independent control on the age of the ignimbrite sequence: an intrusive porphyry to constrain the minimum age of the ignimbrites (sample A), and a large porphyry clast extracted from an ignimbrite breccia to provide a maximum constraint (sample B). In contrast to the ignimbrites, the porphyries were expected to contain simple zircon populations because they contain no visible lithic contamination.

Results

As expected, the two coherent quartz–feldspar porphyry samples (A and B) are free of lithic contamination and contain zircons of uniform age (Fig. 26), indicating their zircon populations contain only magmatic grains and no older xenocrysts. In contrast, the zircon populations of the lithic-contaminated samples have complicated isotopic patterns that reflect inherited components of more than one age.

The ages of the two porphyry samples are identical within analytical uncertainty. They tightly constrain the eruption of the


Gaussian summation of $^{207}Pb/^{206}Pb$ ages
interpreted stratigraphic age 1828.6±5.1 Ma
Sample E syneruptive volcaniclastic sandstone
10% magmatic grains
Sample D lithic-rich ignimbrite
36% magmatic grains
Sample C lithic-poor ignimbrite
60% magmatic grains
Sample B porphyry (clast)
100% magmatic grains
Sample A porphyry (intrusive)
100% magmatic grains
1700 1750 1800 1850 1900 1950 2000
Age (Ma)
Degree of lithic contamination
%
21%
15%
4%
Statistical age of dominant zircon population
n = no. of analyses
c^2 = a measure of goodness of fit of the data; should approach a value of 1 for a good fit.
1863.6±4.4 Ma
n = 13
c^2 = 1.68
1849.9±11.9 Ma
n = 16
c^2 = 1.54
1828.6±5.1 Ma
n = 20
c^2 = 1.14
1828.1±3.5 Ma
n = 19
c^2 = 0.68
1827.3±3.5 Ma
n = 31
c^2 = 0.88
Interpretation of statistical age
Statistical age is of xenocrystic population. Only two magmatic grains were analysed, so the crystallisation age could not be resolved.
Pooled age of two statistically unresolvable populations of inherited grains (~ 1865) and magmatic grains (1826 Ma). Age is geologically meaningless.
Crystallisation age of ignimbrite.
Crystallisation age of porphyry. Constrains the maximum age of the ignimbrite sequence.
Crystallisation age of porphyry. Constrains the minimum age of the ignimbrite sequence.

ignimbrite sequence between 1828.1 ± 3.5 and 1827.3 ± 3.5 Ma. Only one ignimbrite sample containing the least amount of xenolithic contamination (sample C) yielded a well-defined magmatic age of 1828 Ma (sample C). In this lithic-poor ignimbrite, 60 per cent of the 33 grains selected for analysis are of magmatic origin, and the combined analyses of these grains indicate that the melt-precipitated zircons crystallised at 1828.6 ± 5.1 Ma. In contrast the inheritance is so pronounced in the zircon populations of the two samples with the highest degree of lithic contamination that their magmatic ages could not be determined. It is important to note that inherited grains dominate the zircon populations of these lithic-rich samples, even though the analytical strategy was to target melt-precipitated grains. This is because the inheritance is dominated by the youngest xenocrystic population, which could not be detected optically because the zircons comprise euhedral, prismatic, oscillatory-zoned magmatic grains with a similar form to the melt-precipitated 1828-Ma grains.

It is the presence of this youngest xenocrystic population that complicates the interpretation of the data in the most contaminated samples. The significantly older inherited grains do not present a problem as they can be clearly identified as xenocrysts and not part of the melt-precipitated zircon population. The youngest xenocrystic population however, has a weighted mean age of 1865 ± 3 Ma, which is only ~40 m.y. older than the melt-precipitated zircon population (this age is based on the combined analyses of grains belonging to this population from all samples; n = 23, $\chi^2 = 1.34$).

In sample C (lithic-poor ignimbrite), the 1865-Ma xenocrysts did not present a problem when determining the crystallisation age of the sample. Only three 1865-Ma xenocrysts were analysed, and were rejected as statistical outliers to the main crystallisation population, which comprised 20 grains.

In sample D (lithic-rich ignimbrite) however, roughly equal proportions of melt-precipitated grains and grains belonging to the 1865-Ma xenocryst population were analysed (9 and 7 grains respectively). The combined 16 analyses of the two age groups yielded a weighted mean age of 1849.9 ± 11.9 Ma. The χ^2 value of 1.54 for the 16 analyses indicates they conform to a single statistical population. Despite this fact, the gaussian histogram for this sample shows excess scatter for a single peak. The data are clearly skewed towards lower $^{207}Pb/^{206}Pb$ ages, and do not approach a normal distribution as a single statistical population should. If this sample were analysed in isolation, this bias towards lower ages would probably have been attributed to Pb-loss, and the statistical age of 1849.9 ± 11.9 Ma would have been accepted as the crystallisation age of the ignimbrites.

In the context of the other samples, this age is too old, and the data are interpreted in an entirely different manner. The single statistical population is interpreted to comprise two age groupings which can be seen on the gaussian histogram, but cannot be statistically resolved. The statistical population can be deconvolved into two components which have ages of 1861.9 ± 15.7 Ma (based on the 7 oldest grains) and 1810.3 ± 26.8 Ma (based on the 9 youngest grains). These two age groupings are interpreted to represent the 1865-Ma xenocrystic population, also apparent in samples C and E, and the magmatic zircon population respectively. The interpreted magmatic population is younger than the crystallisation age of the sequence as defined by the porphyries and ignimbrite sample C (1828 Ma), but is based on only nine analyses, and the large error indicates the age is poorly defined. If the nine analyses are combined with data from the other ignimbrite sample (C), they statistically conform to the normal population at 1828 Ma.

In the syneruptive volcaniclastic sandstone (sample E), which contains the most lithic contamination of all samples analysed, the inherited population has an even more significant influence on the analytical results, as the dominant zircon population comprises 1865-Ma xenocrysts. Only two of the grains analysed were identified as possibly belonging to the magmatic zircon population. These two grains were identified as statistical outliers to the main zircon population at 1863.6 ± 4.4 Ma (based on 13 xenocrystic grains). If this sample had been analysed in isolation, the main zircon population would not have been recognised as xenocrystic, and the age of the Pul Pul Rhyolite would have been taken to be 1863.6 ± 4.4 Ma, which is ~40 m.y. too old.

Conclusions and implications

The U–Pb analysis of the different facies of the Pul Pul Rhyolite has shown that:

- the ignimbrites and intrusive quartz–feldspar porphyries are essentially comagmatic, and crystallised at 1828 Ma, and
- the country rock incorporated into the ignimbrites and volcaniclastic rock contained sources of more than one age, including one ~40 m.y. older than the Pul Pul Rhyolite sequence.

The age of this inherited population is interpreted to be ~1865 ± 3 Ma. The stratigraphic age of the Pul Pul Rhyolite is taken from the magmatic population of the lithic-poor ignimbrite, which is 1828.6 ± 5.1 Ma.

The results of this study have two important implications for the dating of ignimbrites and other facies which contain significant crustal contamination:

- Firstly, it is important to minimise the degree of lithic contamination in samples selected for geochronological analysis. The study has shown that the crystallisation age of the samples can become more difficult to interpret as the degree of lithic contamination increases.
- Secondly, when interpreting the age of samples containing multiple age populations, the geochronological data cannot be considered in isolation from other data sets and available geological constraints. Without the independent geological constraints on the age of the volcanic sequence supplied by the porphyry samples, the age of the most lithic-rich clastic samples would have been misinterpreted.

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